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EVALUATION AND DOCUMENTATION OF MECHANICAL RELIABILITY OF CONVENTIONAL WASTEWATER TREATMENT PLANT COMPONENTS

by

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Contract No. 68-03-2712

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This study was initiated to determine the in-service reliability, maintainability and availability of selected critical wastewater treatment plant components. Components were considered critical if their failure caused an immediate impact on effluent quality.

Treatment plant components selected included pumps, power transmissions, motors, compressors, valves, and controls. Components were those from four types of wastewater treatment plants. The four types of plants were air activated sludge, oxygen activated sludge, trickling filter, and rotating biological contactor (RBC). Operation and maintenance data obtained from nine operating plants were used to estimate failure rates, mean-time-between-failures, mean-time-to-repair, and availability for each component. These performance statistics are by component type, size range, and application. Performance statistics were calculated from operating data for 119 pumps, 249 power transmissions, 285 motors, 17 compressors, 13 valves, and 269 controls.

Calculated performance statistics can be utilized by design engineers and plant operators to assist in the selection of new equipment. The development of a performance data base and subsequent proper utilization of the data should result in improvements in treatment plant performance. These data allow estimates to be made of performance to be expected from certain equipment in certain applications.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

In the report, performance statistics for various mechanical components found in four types of secondary wastewater treatment plants are presented. These statistics were derived utilizing equipment service records from nine wastewater treatment plants. Results indicate a wide range of performance characteristics for similar equipment in different applications. Example problems are presented with appropriate solutions to explain how these types of statistics can serve as a valuable design and operations tool.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

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ABSTRACT

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Calculated performance statistics can be utilized by design engineers and plant operators to assist in the selection of new equipment. The development of a performance data base and subsequent proper utilization of the data should result in improvements in treatment plant performance. These data allow estimates to be made of performance to be expected from certain equipment in certain applications.

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LIST OF ABBREVIATIONS

Abbreviations

POTW -- Publicly Owned Treatment Works
EPA -- Environmental Protection Agency
GAO -- General Accounting Office
BOD -- biochemical oxygen demand
MTBF -- mean time between failure
MTTR -- mean time to repair
WRAP -- Wastewater Reliability Analysis Program
PM -- preventative maintenance
CM -- corrective maintenance
AVI -- inherent availability
AVO -- operating availability

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This work was supported by the U.S. Environmental Protection Agency, Wastewater Research Division, under Contract 68-03-2712. Mr. Jon H. Bender of the EPA Municipal Environmental Research Laboratory, Cincinnati, Ohio, was the Project Officer. The authors wish to acknowledge the help of Messrs. John Smith, Frank Evans and Ms. Janet Houthoofd of the EPA, and especially the help and support of Mr. Jon Bender who worked closely with project personnel throughout the project. The assistance of plant personnel at the wastewater treatment plants visited during this project is also acknowledged.

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SECTION 1

INTRODUCTION

There are approximately 21,000 publicly owned municipal treatment plants (POTWs) operating in the U.S. at the present time, with 1000-1200 new plants being constructed each year(1)(2). Since 1957, Federal grants exceeding 20 billion have been awarded to help state and local governments construct these treatment plants. Once constructed, local governments become responsible for plant operation in accordance with effluent discharge permit requirements established by the National Pollutant Discharge Elimination System (NPDES).

Many POTWs are apparently not meeting NPDES permit requirements. The General Accounting Office (GAO) concluded in 1970 that operation and maintenance problems with POTWs had been widespread for many years and had resulted in inefficient plant operations(3). A 1975 EPA analysis of 954 POTW inspections showed 386 plants had sufficient design and operational performance data to determine whether the plant was meeting design criteria for biochemical oxygen demand (BOD) removal. 40 percent of the 386 plants failed to meet design BOD removal. 49 percent of 305 plants were operating below design criteria for suspended solids removal. Other studies have indicated significant problems of non-compliance by POTWs with NPDES permits(4)(5)(6).

In recognition of these operational and maintenance problems, the U.S. EPA initiated a national research program dealing with performance and reliability of POTWs. A significant part of the effort involves determining the reliability of various mechanical components used at POTWs.

This study was conducted to quantify the in-service reliability of critical mechanical components found in four types of secondary wastewater treatment plants. The four types of plants included in this study were air activated sludge, oxygen activated sludge, trickling filter, and rotating biological contactor. Component reliability statistics calculated were mean time between failure (MTBF), mean time to repair (MTTR), and availability as a fraction of scheduled operating time.

To determine the in-service reliability of critical mechanical components, the first step was to identify the critical components. The following components were identified as critical (i.e., failure would have an immediate impact on effluent quality):

(1) Pumps
(2) Power transmissions
(3) Motors

(4) Compressors
(5) Diffusers
(6) Valves
(7) Controls
(8) Pressure vessels
(9) Conveyors.

A criticality analysis was then conducted to determine which applications of these components should be included in the study. This effort served to identify the field data collection requirements.

Nine treatment plants were then selected from a candidate list of approximately 40 plants. These nine plants were visited and data collected from plant maintenance records. Reliability statistics were then calculated using these data.

SECTION 2

CONCLUSIONS

Based upon the results of the performance data collection and analysis effort conducted during this project, the following conclusions are made:

(1) Three types of performance statistics (reliability, maintainability, and availability) have been determined for mechanical components of wastewater treatment plants. (p. 25)

(2) These performance statistics were not available in the literature, from manufacturers, or owners of equipment. (p. 31)

(3) These performance statistics can be used by design engineers as a tool to (a) compare and predict performance of generic equipment in various applications, and (b) design reliability into new treatment plants. (p. 33)

(4) These data can be used by operators of wastewater treatment plants to help develop spare parts inventories for new equipment and establish preventative maintenance programs. (p. 37)

(5) The majority of the 200 plants contacted by phone or visited during the screening process did not maintain adequate records necessary for collection of data needed in this study. (p. 14)

(6) This data base does not cover all the size ranges or types of equipment typically found in the 21,000 treatment plants operating in the U.S. Therefore, performance statistics for many of the components found in smaller plants are not available in the data base. It was found that these records are not routinely kept by the smaller plants surveyed during this study. (p. 14)

(7) The quality of data obtained from the nine treatment plants was good. The form of record keeping sometimes required judgments as to appropriateness with respect to project data requirements. (p. 16)

(8) The nine treatment plants from which the data were collected maintained records for equipment for a variety of reasons, including ordering spare parts, scheduling preventative maintenance, and preparing annual budgets.

(9) The nine plants visited had preventative maintenance programs which appeared to be effective.

(10) Performance statistics can provide design engineers and plant operators with additional information to help select and specify equipment. Training will be required to help these people know how to utilize such data. For maximum effect, the data base should be expanded to cover all major types and size ranges of equipment found at treatment plants presently operating in the U.S. The data base should be maintained for at least a five year period.

SECTION 3

RECOMMENDATIONS

Based upon the results of this study, the following recommendations are offered:

(1) EPA should encourage the use of performance results of this study by designers or operators as an additional tool for the selection of equipment and the prediction of performance from mechanical components.

(2) EPA should conduct a series of technical seminars to (1) present the results of this project to design engineers and plant operators, and (2) explain the basic reliability and availability analysis methodologies. Their feedback could be used to help formulate and define future EPA policy regarding the Federal role in the WWTP performance statistic data base management.

(3) EPA should conduct a study to determine the feasibility of implementing a continuous performance data collection program from selected treatment plants representing a sufficient cross section of the nearly 21,000 plants in the U.S. by plant type and design flow. Mechanism and cost should be determined.

(4) Based upon favorable results of recommendations (2) and/or (3) above, EPA should initiate a program to collect performance data on a continuous basis for use by design engineers and treatment plant operators.

SECTION 4

PROJECT OBJECTIVES

Major project objectives were as follows:

(1) Quantify in-service reliability, maintainability and availability on mechanical components used in four types of secondary wastewater treatment plants.

(2) Show how the component application affects its reliability, maintainability and availability.

(3) Quantify in-service reliability, maintainability and availability of the sludge processing unit operations at wastewater treatment plants.

SECTION 5

RESEARCH APPROACH

The research approach utilized to accomplish the objectives of this study involved a series of major tasks which are discussed in detail in the following sections. Briefly, the first step, the Criticality Analysis, involved the identification of the important mechanical components in conventional secondary wastewater treatment plants as defined by their potential impact on effluent quality should they fail. Once these components were identified, the criticality of each component was determined and ranked by conducting a failure mode and effects analysis. From this effort, the desirable information needed from actual operating treatment plant records was identified.

The Plant Selection step involved developing a candidate list of treatment plants to be visited. From this list, nine treatment plants were selected and subsequently visited to collect data. These data were then analyzed to determine the important performance statistics, i.e., mean time between failure, mean time to repair, and availability.

5.1 CRITICALITY ANALYSIS

The objective of the criticality analysis was to determine the mechanical components in conventional wastewater treatment plants which would have the most immediate impact on final effluent quality if they failed.

The procedure used in this phase was to define the conventional secondary wastewater treatment plants - air activated sludge, oxygen activated sludge, trickling filter and rotating biological contactor in terms of the respective flow diagrams. These flow diagrams are presented as Figures 1 through 4.

Sludge processing systems were included in the study. These included vacuum filters, aerobic and anaerobic digestion and dissolved air flotation. Data for components of sludge processing equipment were not collected. Only data for those sludge processing systems found at the treatment plants visited were collected.

The flow diagrams defined the various treatment systems of interest. Each system was then divided into the following unit operations:

- Headworks
- Primary settling
- Secondary treatment (biological units)
- Final settling

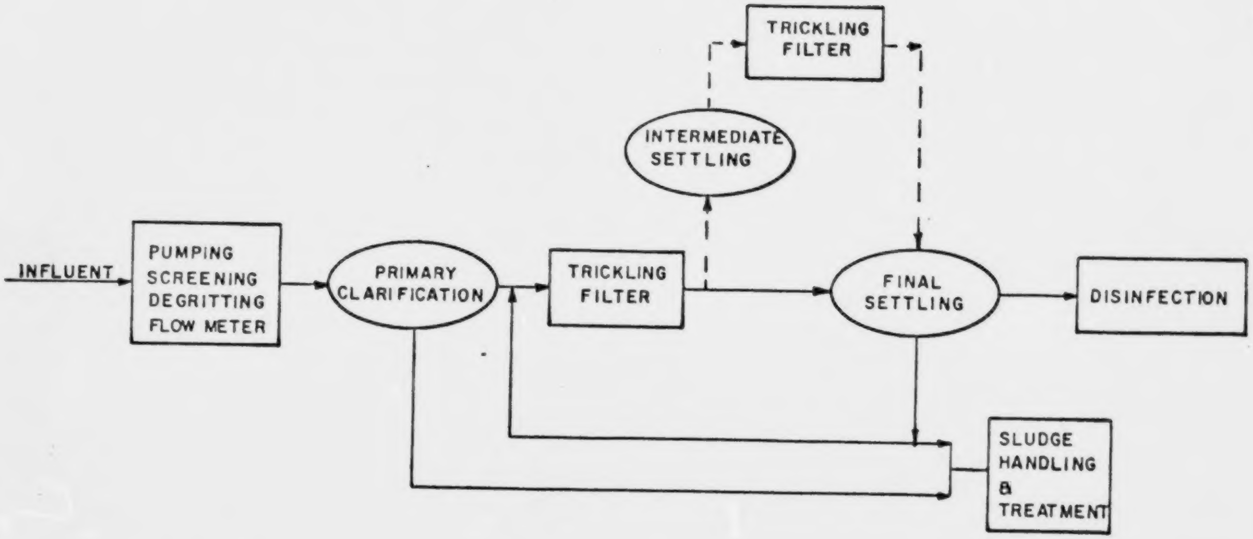
INFLUENT
PUMPING
SCREENING
DEGRITTING
FLOW METER
PRIMARY
CLARIFICATION
TRICKLING
FILTER
INTERMEDIATE
SETTLING
TRICKLING
FILTER
FINAL
SETTLING
DISINFECTION
SLUDGE
HANDLING
&
TREATMENT

FIGURE 1

FLOW DIAGRAM – TYPICAL TRICKLING FILTER SYSTEM

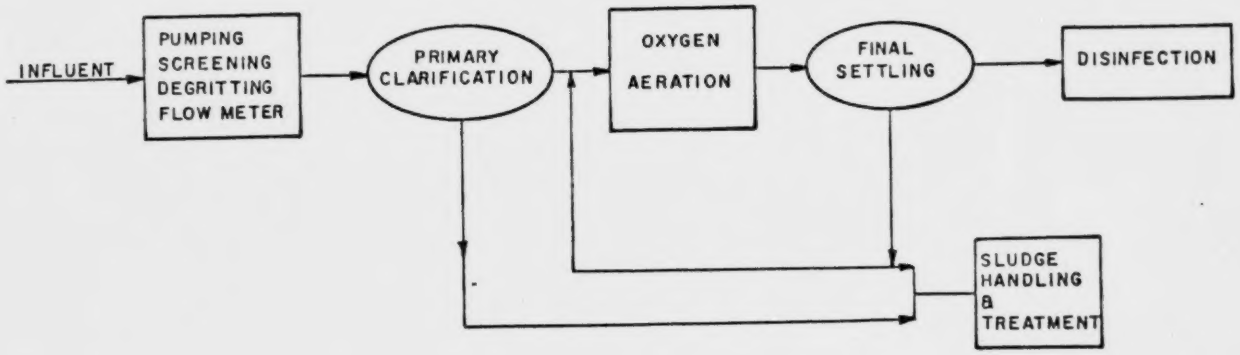
INFLUENT
PUMPING
SCREENING
DEGRITTING
FLOW METER
PRIMARY
CLARIFICATION
OXYGEN
AERATION
FINAL
SETTLING
DISINFECTION
SLUDGE
HANDLING
&
TREATMENT

FIGURE 2

FLOW DIAGRAM — TYPICAL OXYGEN ACTIVATED SLUDGE SYSTEM

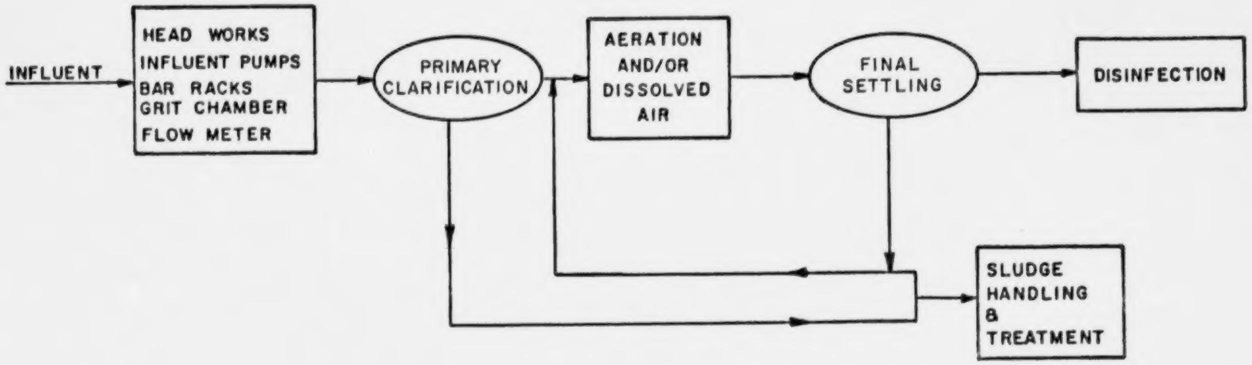
INFLUENT
HEAD WORKS
INFLUENT PUMPS
BAR RACKS
GRIT CHAMBER
FLOW METER
PRIMARY CLARIFICATION
AERATION AND/OR DISSOLVED AIR
FINAL SETTLING
DISINFECTION
SLUDGE HANDLING & TREATMENT

FIGURE 3

FLOW DIAGRAM – TYPICAL ACTIVATED SLUDGE TREATMENT SYSTEM EXAMPLE

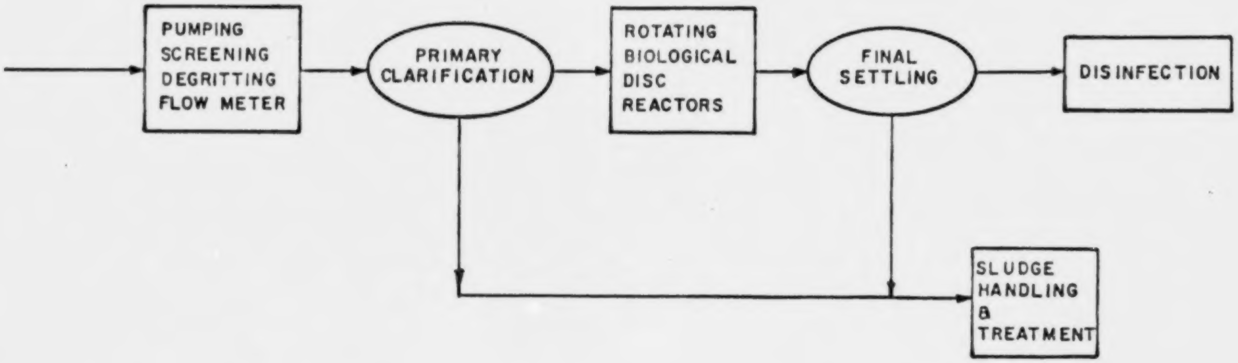
PUMPING
SCREENING
DEGRITTING
FLOW METER
PRIMARY
CLARIFICATION
ROTATING
BIOLOGICAL
DISC
REACTORS
FINAL
SETTLING
DISINFECTION
SLUDGE
HANDLING
&
TREATMENT

FIGURE 4

FLOW DIAGRAM — TYPICAL ROTATING BIOLOGICAL CONTACTOR TREATMENT SYSTEM

- Sludge processing
- Disinfection

The broad classifications of mechanical equipment that could be identified in each unit operation were then defined. These classifications are:

Pumps
Power transmission
Motors
Compressors
Diffusers (air/water)
Valves
Controls
Pressure vessels
Conveyers (unconfined materials handling)

A numbering system was developed to aid in performing the criticality analysis and data collection. The numbering system is presented in Appendix A. In developing the numbering system, the generic groups, applications, size ranges, subcomponents and other pertinent information were preliminarily identified. Examples of these categories are presented in Appendix A. The system was developed with the flexibility to add additional information during field collection of data. This is the reason for the use of the two, three and four digit columns to identify a specific component. Additionally, to allow for data sorting by computer, it was necessary to eliminate any mixing of equipment type or application between columns.

The following steps were then used in the criticality analysis:

(1) Identification of the broad classification in each plant unit operation for each type of plant.

(2) Identification of the applications for each broad classification defined in step 1 above.

(3) Assignment of a criticality factor as a function of failure on effluent quality and the time of the effect.

In performing the criticality analysis, it was assumed that there was no equipment duplication and the plant was operating at design conditions. For example, it was assumed that there was only one raw wastewater pump in the headworks, only one final clarifier in the final settling unit operation, and no additional hydraulic capacity in either component.

A rating was assigned to each plant type, unit operation, broad classification and application combination. The rating consisted of two parts:

(1) Relationship between Failure and Effluent Quality

- A - Significant impact
- B - Minimal impact
- C - No impact

(2) Time Factor

- 1 - 0-4 hours
- 2 - >4-12 hours
- 3 - >12-24 hours
- 4 - >24 hours

Using this approach, if a combination was rated "A-1," the failure of the mechanical component would likely result in a significant impact on effluent quality within four hours. If the rating was "C," the failure would probably have no impact on effluent quality. The results of the criticality analysis are presented in Appendix B.

The results of the criticality analysis were then reviewed and ranked according to priority by those that would have the most significant impact in the shortest time period. The results of this ranking are presented in Appendix C.

The critical components for inclusion in the study were selected as those with an assigned criticality factor of either A-1, A-2, A-3 or B-1. If the impact of failure of a mechanical component was minimal (i.e., B) and it occurred within four hours, that component was also considered to be critical and included in the data collection effort. The following presents a summary of those mechanical components selected for inclusion in the data collection phase:

- Raw and intermediate wastewater pumps, power transmission and motors for all plant types

- Return activated sludge pumps, power transmission and motors for air and oxygen activated sludge

- Recirculation pump, power transmission and motors for trickling filter and rotating biological contactors

- Motors and power transmission for final clarifiers for all plant types

- Motors, power transmission, compressors, valves, controls and diffusers used in dissolved air production application and mechanical aerators in air activated sludge plants

- Motors, power transmission, recirculation pumps, controls, diffusers and valves used in oxygen generation, application and recirculation in oxygen activated sludge plants

- Liquid application systems for trickling filter plants

- Compressors, motors, power transmission and controls used in rotating biological contactors in RBC plants

- Motors, pumps, power transmission and controls used in primary clarifiers and primary sludge pumping in trickling filter and RBC plants

- Recirculation pumps controls used in secondary treatment in RBC plants

- Raw and intermediate wastewater pump controls used in all plant types and valves used in raw and intermediate pumps in trickling filter plants

- Controls used in dosing siphon in secondary treatment in trickling filter plants

- Controls used in final clarifiers for all plant types

- Pumps, motors, power transmission and pressure vessels used in disinfection for all plant types.

Having defined the data collection requirements, the next step involved the selection of treatment plants having adequate records from which these data could be collected.

5.2 DATA SOURCE SELECTION

The Criticality Analysis described in Section 5.1 defined the mechanical components for which performance data were needed. The next step was to select the treatment plants where this information could be obtained. This data source selection process involved the following tasks:

- o Develop a list of candidate plants.
- o Select plants for one-day screening visits.
- o Conduct the one-day visits.
- o Select study plants.

A candidate list of approximately 200 treatment plants was developed utilizing information from the U.S. EPA staff, equipment manufacturers and sales representatives, SwRI and subcontractor contacts, treatment plant operators and the literature. The criteria used to develop this list were primarily (1) that the plants satisfied the plant type requirement (i.e., air or oxygen activated sludge, RBC, or trickling filter); (2) there was an indication these plants would be willing to participate in the study; and (3) maintenance records were available.

Using information about these plants, forty-two plants were selected for direct contact by telephone. Project objectives and available maintenance records were discussed with appropriate personnel at each facility. The majority of the plants contacted did not maintain historical records on the plant components by component type. To access these data, extensive on-site time would have been necessary. Other plants did not maintain maintenance records. This was more often the case with smaller plants. Seventeen plants were identified for further consideration. One-day screening visits were then scheduled for each plant. The one-day visits were made to discuss the project with plant personnel and verify the suitability of plant records for the study.

Following the one-day visits, the treatment plants to be included in the data acquisition effort were selected. Criteria used to make the selection were as follows:

(1) Existence of adequate and complete preventative and corrective maintenance records for all major equipment components at each plant;

(2) Existence of plant equipment typical of the generic equipment found in the four types of treatment plants under consideration;

(3) An indication that plant operations and maintenance personnel were willing to cooperate in the data collection effort.

Table 1 shows the design flow and age of the nine plants included in this study.

TABLE 1. TREATMENT PLANTS INCLUDED IN RELIABILITY STUDY

Plant Type	Design Flow (MGD)	Age (Years)
Air Activated Sludge	98	15
	75	7
	36	8
	60	4
Oxygen Activated Sludge	72	5
	300	7
Trickling Filter	45	20
	150	30
Rotating Biological Contactor	24	2

5.3 DATA ACQUISITION

The objective of the data acquisition phase of this study was to obtain failure and maintenance data on the critical mechanical component/application combinations shown in Appendix C, "Mechanical Equipment Priority Ranking" (see Section 5.1). A schedule was developed for visiting the plant locations identified in Section 5.2. Plant managers/superintendents were contacted to establish the time for the visit and confirm that the appropriate plant employees would be available at that time.

Upon arrival at each plant, the data collection team (engineer/operator and engineering technician) met with the plant staff involved. This meeting provided an opportunity for the data collection team to further explain the project and discuss possible uses of the project results. The methodology of the data collection effort was discussed. The plant staff was asked to outline the details of their maintenance management system, work order system, spare parts program, contract maintenance, and problems encountered. These discussions were important to facilitate proper collection of the data from plant records. Following this interview, a plant tour was made to familiarize the data collection team with plant layout, sub-processes, equipment, flow patterns, flow rates, and controls.

At this point, data collection was started. Maintenance records for each critical component were reviewed. Data collection forms were used to code all data. An example is shown in Figure 5. Required data elements are shown at the top of this form. All data collected in the field were encoded using the numbering system discussed in Section 5.1 (see Appendix A). These codes are shown in the appropriate columns in Figure 5. For example, column one contains the code number 04-8731. The first two digits, 04, identify the plant location. The second four-digit number represents a record number used to identify that specific piece of equipment. Column two, plant type, shows the number 05, which identified this plant as a combination air/oxygen activated sludge plant. Codes for each of the remaining 23 columns are shown, with a description of what each code means shown below the code. Column 23 was for recording actual down time of sludge processing systems. Data for the sludge processing systems at each facility visited were recorded as shown at the bottom of Figure 5. These data allowed calculation of the mean time between failure and availability of the system.

The data collection from plant records often required a degree of judgment and interpretation. This was especially true when deciding when equipment had actually failed. A mechanical component failure is classified as an event which occurs when a subcomponent ceases to perform its function, and must be repaired or replaced to restore the component to a normal operating condition. An example of a failure is a seized bearing on a pump shaft which must be replaced before the pump can be restored to an operating condition. In contrast, an equipment malfunction was defined as situations where the equipment could be placed back into service by minor cleaning and/or adjustments. Only data for down time considered to be caused by failure were recorded. Malfunctions including pump blockages, reduction in blower capacities due to dirty air filters, and plugging of air diffusers were not recorded. If interpretation of maintenance records was questionable, the data collection team conferred with plant maintenance staff to decide whether a failure had occurred.

5.4 DATA ANALYSIS

A computer program entitled "Wastewater Reliability Analysis Program - WRAP" was written to handle the sorting and analysis of the relatively large data base. Complete details of the logic, fortran listings, and capabilities of WRAP are contained in Appendix E of this report. Reliability, maintainability, maintenance and availability statistics were calculated from the data base across all plants for:

SLUDGE PROCESSING EQUIPMENT		WASTEWATER TREATMENT EQUIPMENT		
PLANT NO. 4 UNIT NUMBER	04 - 4321	PLANT NO. 4 UNIT NUMBER	04 - 8731	PLANT LOCATION
COMBINATION AIR/OXYGEN ACT. SL.	05	COMBINATION AIR/OXYGEN ACT. SL.	05	TYPE 2
INCINERATOR	10	SECONDARY TREATMENT	03	UNIT OPERATION 3
		PUMPS	01	BROAD CLASSIFICATION 4
		PUMP PROPELLER AXIAL	0114	GENERIC GROUPS 5
		INTERMEDIATE WASTEWATER PUMP	03	APPLICATION 6
		100,000 G.P.M.	04	SIZE 7
		BEARING, BALL DOUBLE ROW	023	SUB-COMPONENT 8
		EFFLUENT IMPACT WITHIN 4 HOURS	01	CRITICALITY 9
JULY, 1976	0776	JULY, 1977	0777	DATE INSTALLED 10
100%	99	100 %	99	% OPERATING TIME * 11
11 FAILURES	11	1 FAILURE	01	FAILURES 12
		NOT KNOWN	00	FAILURE MODE 13
		NORMAL WEAR	08	CAUSE OF FAILURE 14
		24 - 168 HOURS	04	DOWN TIME 15
		6 HRS. - 24 HRS.	03	TIME TO REPAIR 16
		DRY BASEMENT	04	ENVIROMENTAL FACTOR 17
		REPLACED	02	PART DISPOSITION 18
		NOT KNOWN	000	SUBCOMPONENT MFR. 19
		ALLIS CHALMERS	006	COMPONENT MFR 20
		NOT KNOWN	00	PART INV. INFO 21
		CORRECTIVE MAINTENANCE	02	TYPE OF MAINT 22
DOWN TIME 1,584 HOURS	1584			DOWN TIME OF UNIT OP (SL Only) 23
AUGUST, 1979	0879	AUGUST, 1979	0879	COLLECTION DATE 24
		8 HOURS	0008	CLOCK TIME TO REPAIR 25

Figure 5. Sample of a Field Data Collection Form

(1) Components
(2) Components by application
(3) Components by size
(4) Components by generic group
(5) Components by generic group by application
(6) Components by generic group by size.

In addition, failure distribution information by subcomponent type for the first four categories listed above were also calculated. Also, reliability and availability statistics were calculated for sludge processes.

Included in Appendix E is a computer printout by plant, and across all plants of reliability, maintainability, maintenance and availability statistics for components by generic group by application by size.

The statistics calculated from the data serve as the best summary of the data base in terms of the reliability, maintainability, maintenance, availability and subcomponent failure distribution parameters for the nine wastewater treatment plants. This information should be useful to other plant owners and operators, equipment manufacturers, and plant designers.

A description of the algorithms and methods used to calculate the estimates of the parameters which appear in the tables in Appendix D of this report follows.

5.4.1 Number of Units

The number of units in the data base for each category of component groupings was calculated by summing the number of units reported in the data base across the appropriate grouping.

5.4.2 Number of Failures

The number of failures (Column 12 in Figure 5) was calculated in the same manner as the number of units.

5.4.3 Operating Hours (in millions of hours)

The total operating hours (OH) for the units in each category of component groupings was calculated by the following formula:

$$OH = (8760 \sum_{i=1}^{N} Y_i P_i)/1,000,000 \qquad ,$$

where

Y_i is the number of years between the installation date (Column 10 in Figure 5) and the date the data were taken or the unit was taken out of service (Column 24 in Figure 5), for the i^{th} unit in the category,

P_i is the percent of the time the unit was operating (Column 11 in Figure 5), and

N is the number of units in the category.

5.4.4 Overall MTBF (in millions of hours)

The point estimate for the overall mean-time-between-failures (MTBF) was calculated by the following formula:(7)

$$\text{MTBF} = \frac{2T}{X^2_{0.5;2r+2}}$$

where,

T is the total operating hours (OH) from Section 5.4.3,

r is the number of failures from Section 5.4.2, and

$X^2_{0.5;2r+2}$ is the value of a chi-square distribution(7) with 2r+2 degrees of freedom at the fiftieth percentile.

This method yields a slightly more conservative estimate of the MTBF than the usual method of dividing the operating hours by the number of failures. This method also allows an estimate of the MTBF, even when no failures have occurred.

5.4.5 Minimum MTBF (in millions of hours)

The minimum MTBF for a particular category is the least MTBF calculated in a subcategory of the category. For example, in a grouping of components by generic group by size, there may be several subcategories by application. The smallest value of MTBF from this subcategory is listed as the minimum MTBF. This information serves as a lower bound on the range of the subcategory MTBF's. Where there is only one data point in the subcategory, the entry is left blank.

5.4.6 Maximum MTBF (in millions of hours)

The maximum MTBF is calculated in a similar manner to the minimum value and serves as an upper bound on the range of subcategory values. The difference between the maximum and minimum values can be interpreted as a measure of dispersion about the overall MTBF estimate. If one assumes that these estimates are normally distributed,(8) then an estimate for the standard deviation is one-sixth of the range of the minimum to maximum values. The smaller the ratio of the estimate of the standard deviation to the MTBF, the more precise is the estimate of the MTBF.

5.4.7 Overall 90% Confidence Level (in millions of hours)

The overall 90% confidence level (M(.90)) for the MTBF is calculated by the formula:(7)

$$M(.90) = \frac{2T}{X_{2}\,{}_{.90;2r+2}} ,$$

where,

T is the total operating hours (OH) from Section 5.4.3,

r is the number of failures from Section 5.4.2, and

$X^2_{.90;2r+2}$ is the value of a chi-square distribution with 2r+2 degrees of freedom at the ninetieth percentile.

The meaning of the 90% confidence limit is that one can be 90% confident that the true value of the MTBF is at least as great as the calculated 90% confidence limit.

The percent deviation of the confidence limit value from the point estimate value of the MTBF is a function of the number of failures.(7) Figure 6 is a graph showing the percent deviation from the point estimate of the lower confidence limit, as a function of the number of failures. Figure 6 was derived using the following formula:

$$\text{Percent Deviation} = 1 - \frac{x^2(.5);\ (2r+2)}{x^2(CL);\ (2r+2)}$$

From Figure 6, for a lower 90% confidence limit, the following information can be derived as to the approximate percent deviation of the lower 90% confidence limit from the point estimate of the MTBF as a function of the number of failures.

Number of Failures	Approximate Percent Deviation
1	-57%
2	-49%
3	-44%
4	-41%
5	-38%
10	-31%
20	-24%
100	-12%

The percent deviation is also a measure of the precision of the point estimate.

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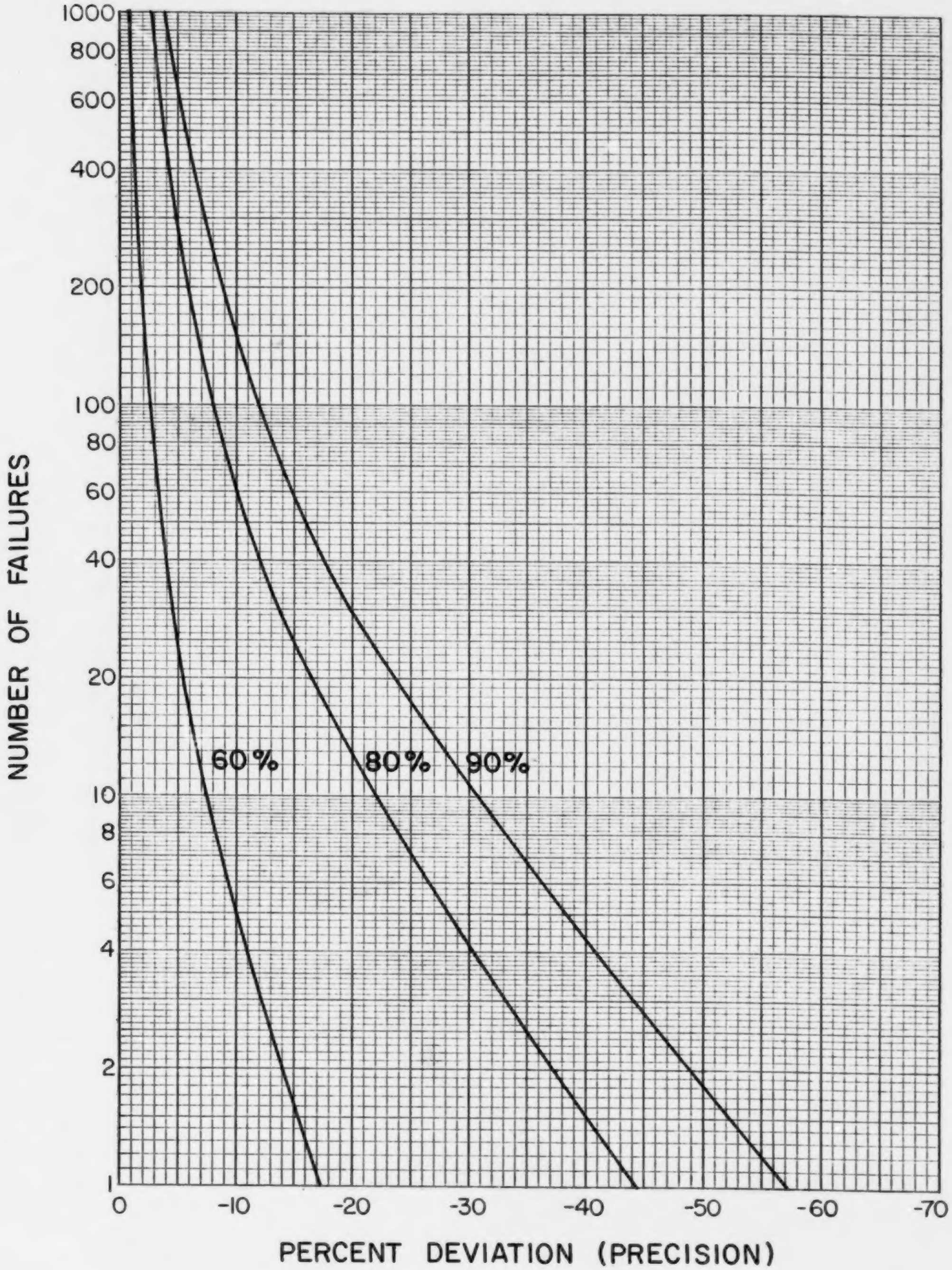

Figure 6. Percent Deviation of One Sided Lower Confidence Limits From Point Estimate of MTBF vs. Number of Failures

Fig 7

title [illegible] side

5.4.8 Preventative Maintenance Hours per Unit per Year (PM-HRS/UNIT/YEAR)

The preventative maintenance (scheduled maintenance) hours per unit per year (PH) for each unit category are calculated by the formula:

$$PH = \left(\sum_{p=1}^{m} PM_j\right)/[(Y)(m)] \quad ,$$

where,

- m is the number of units in the category, (taken from Section 5.4.1)
- Y is the number of operating years on the m units (taken from Section 5.4.3), and
- PM_j is the number of preventative maintenance hours reported on the j^{th} unit.

5.4.9 Corrective Maintenance Hours Per Unit Per Year (CM-HRS/UNIT/YEAR)

The corrective maintenance (unscheduled maintenance due to failures) hours per unit per year (CH) for each category are calculated by the formula:

$$CH = \left(\sum_{j=1}^{m} CM_j\right)/[(Y)(m)] \quad ,$$

where,

- m is the number of units in the category (taken from Section 5.4.1)
- Y is the number of operating years ($\Sigma Y_i P_i$, taken from Section 5.4.3) on the m units
- CM_j is the man hours spent on corrective maintenance for the j^{th} unit (Column 16 in Figure 5).

5.4.10 Mean-Time-To-Repair (MTTR) in hours

The mean time to repair a unit in a category is calculated by the formula

$$MTTR = \left(\sum_{j=1}^{N} \sum_{i=1}^{nj} C_{ij}\right)/\left(\sum_{j=1}^{N} \sum_{i=1}^{nj} r_{ij}\right)$$

where,

N is the number of units in the category,

n_j is the number of corrective maintenance actions due to failures on the j^{th} unit

C_{ij} is the number of calendar hours during which repair actions were being made (Column 15 in Figure 5) due to the i^{th} failure on the j^{th} unit.

r_{ij} is the i^{th} failure on the j^{th} unit, that is,

$\sum_{j=1}^{N} \sum_{i=1}^{nj} r_{ij}$ is the total number of failures

(or corrective maintenance actions) on the N units in the category.

5.4.11 Inherent Availability (AVI)

The inherent availability for each of the component groupings is calculated by the formula:

$$AVI = \frac{MTBF}{MTBF+MTTR}$$

The inherent availability of a component is a measure of the fraction of time that the component can be expected to be operational, excluding preventative maintenance downtime.

5.4.12 Operating Availability (AVO)

The operating availability for each of the component groupings was calculated by the formula:

$$AVO = \frac{TH-THD}{TH} \quad ,$$

where,

$TH = (\sum_{i=1}^{N} Y_i)(8760)$ = total hours for all units in category, and

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THD = total downtime over all units due to corrective and scheduled maintenance.

Thus, the operating availability is calculated from the operating history of the units, and is a measure of the fraction of the calendar time which the unit was operating.

5.4.13 Component Failure Statistics by Subcomponent Type

For each of the first four component groupings listed in Section 5.4, the number of failures of the components due to failures of subcomponents was determined. The relative frequency of failures by subcomponent type was calculated. These frequency distributions for the dominant subcomponent failures are listed in Appendix D, Part 2.0.

5.4.14 Reliability and Availability Statistics for Sludge Processes

Data on the following five sludge process were obtained.

(1) Sludge treatment external to the wastewater treatment process
(2) Anaerobic digestion
(3) Incineration
(4) Sludge Thickening Dissolved Air Floatation
(5) Vacuum filter

Statistics calculated by plant and across all plants are: operating hours, number of failures, MTBF, 90% confidence limits on MTBF and operating availability. These statistics for sludge processes were calculated in a manner similar to their counterparts for components, and are presented in Appendix D, Part 3.0.

SECTION 6

RESULTS AND DISCUSSION

The performance statistics on critical components and sludge processes which were calculated from the data gathered at nine wastewater treatment plants are presented in Appendix D. The statistics which were calculated are as follows:

RELIABILITY STATISTICS

- Overall mean time between failures (Overall MTBF)
- Maximum mean time between failure (Max MTBF)
- Minimum mean time between failure (Min MTBF)
- Lower limit 90% confidence level for the mean time between failure point estimate (overall 90% CL)

MAINTAINABILITY AND MAINTENANCE STATISTICS

- Mean time to repair (MTTR)
- Preventative maintenance man hours per unit per year (PM-HRS/Unit/YR)
- Corrective maintenance man hours per unit per year (CM-HRS/Unit/YR)

AVAILABILITY STATISTICS

- Inherent availability (AVI)
- Operating availability (AVO)

These statistics, presented in Part 1.0 of Appendix D, have been grouped as follows:

- By component (component is synonymous with broad classification as used in the data numbering system)
- By component by generic group
- By component by application
- By component by size/capacity
- By component by generic group by application
- By component by generic group by size/capacity

The definitions and methods used to calculate the performance statistics are presented in Section 5.4 of this report. A discussion of Tables 1.1.1 and 1.1.2 of Appendix D follows.

Table 1.1.1 presents the reliability statistics for the eight components (or broad classifications) included in the data base. The overall point estimate of the mean time between failures for pumps was 32,066 hours, or approximately 3.7 years. This estimate is for all types of pumps of various size ranges in a variety of applications. To obtain the MTBF estimate for a specified type of pump in a certain application, say an open impeller pump being used for raw wastewater pumping, one refers to Table 1.5.1.1. The lower limit 90% confidence level MTBF value for pumps in Table 1.1.1 is 28,630 hours, or approximately 3.3 years. As discussed in Section 5.4, this means there is a 90% chance that the true MTBF value is greater than 3.3 years. The true MTBF value would be that value calculated from operating data for all critical pumps in all wastewater treatment plants throughout the United States. Since this history is not presently available, the 90% value, combined with the overall point estimate, provides a reasonable range for predicting component performance.

The minimum and maximum MTBF values shown in Table 1.1.1 represent the smallest and largest estimated MTBF values calculated for subcategories of pumps. The difference between these values can be interpreted as a measure of the dispersion about the overall MTBF estimate for pumps.

In summary, the estimate of the true MTBF value for pumps based upon data collected is 32,066 hours. The smallest and largest MTBF values calculated were 21,662 hours and 74,191 hours, respectively in the subcategory of generic group. There is a 90% chance that the true MTBF value is at least 28,630 hours. The same conclusions can be made for the other components listed in the tables presented in Part 1.0 of Appendix D.

Table 1.1.2 presents the maintenance statistics for components. For pumps, the preventative maintenance (scheduled) hours/unit/year spent at all the treatment plants included in the study averaged .00227 hours. The corrective maintenance (breakdown) hours per unit per year were .05177 hours. These numbers might appear to be low. However, it must be recognized they are based upon a large number of pumps (119) operating for a combined total of 442 years. Many units operated for ten years with few failures, and required minimal scheduled maintenance. The corrective maintenance value is based upon the active man hours required to disassemble, correct, and reassemble the unit, excluding time parts may have spent in the shop or time spent waiting for a new part to be received.

The AVI, or the inherent availability, is a measure of the fraction of time that the component can be expected to be operational, excluding preventative maintenance downtime. The AVO, or the operating availability, is a measure of the same fraction of time, but is based upon the operating history of the units, including preventative and corrective maintenance.

For pumps, the AVI and AVO fractions from Table 1.1.2 are .99968 and .99116, respectively.

The tables in the other five groups provide a further breakdown of the reliability and maintenance statistics.

Part 2.0 of Appendix D contains tables presenting the number and relative frequency of failures of subcomponents for the eight components or broad classifications. For example, Table 2.1.1 lists the types of subcomponents which caused pump failures, ranked according to the number of failures. There were 17 impeller wear ring or plate failures. The relative frequency was .177. This means one should expect that approximately 17 percent of the subcomponent failures for pumps will be due to impeller wear rings or plates.

Part 3.0 of Appendix D presents reliability and availability statistics for the various sludge processes located at the treatment plants visited during this study. Table 3.1.1 presents for the five sludge processes listed, total operating hours, number of failures of the process, the mean time between failure, the 90% confidence level lower limit and the operating availability. The first process listed, sludge process external to wastewater treatment process, includes primary, secondary, waste activated, and digester gas recirculation pumping. The other processes listed are self-explanatory.

MTBF Comparison Method

In order to select the component type for an application with the highest MTBF, it is necessary to compare the MTBF statistics for the candidate component type. Since one is comparing estimates of the true MTBF, it is useful to derive an estimate of the level at which a given MTBF value is statistically different from another MTBF value.

One method is to utilize an "F" test(8) based on the fact that the statistic

$$\frac{2r^{m}}{m}, \text{ where}$$

r is the number of failures,

^{m} is the print estimate for MTBF, and

m is the true MTBF,

has a Chi Square distribution with 2r degrees of freedom.(7) The ratio of two of these statistics has an "F" distribution(8) with $2r_1$, $2r_2$ degrees of freedom, and a test of the hypothesis that the true MTBF's of the populations from which the estimates came are equal can be made.

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Another less precise method is illustrated in the following paragraphs, using data taken from Tables 1.2.1, 1.5.2.1, and 1.5.2.9.

Generic Group	No. of Failures	MTBF	90% CL
Concentric Reducer	2	122,640	61,898
Belt Drive	5	91,101	55,640

The significance level at which the two MTBF's are statistically different is a measure of the risk that one is wrong in saying that the component with the highest point estimate value MTBF has a true MTBF that is actually higher than the point estimate value MTBF of the other component.

A less precise method (than the F test) for determining the significance level at which the concentric reducer can be judged to have a higher MTBF than the belt drive is outlined below:

Step 1. Compare the 90% confidence limit value MTBF of the concentric reducer to the point estimate value MTBF of the belt drive. If the 90% confidence limit value MTBF of the concentric reducer (61,898 hours) is greater than the point estimate MTBF value of the belt drive (91,101 hours), there is less than a 10% chance of being wrong if one decides that the true MTBF of the concentric reducer is greater than the point estimate value MTBF of the belt drive; the significance level would be less than 10%. However, since the 90% confidence limit value MTBF of the concentric reducer is less than the point estimate value MTBF of the belt drive, one must go on to Step 2 to determine the approximate significance level.

Step 2. Use the graph in Figure 6 to determine the % confidence limit value MTBF of the concentric reducer which is greater than the point estimate value MTBF of the belt drive.

From Figure 6, the deviation from the point estimate for 80% CL with 2 failures is .376, and for 60% CL with 2 failures is .140. The confidence limits are:

$$80\% = (1-.376)(122{,}640) = 76{,}520$$

$$60\% = (1-.140)(122{,}640) = 105{,}460$$

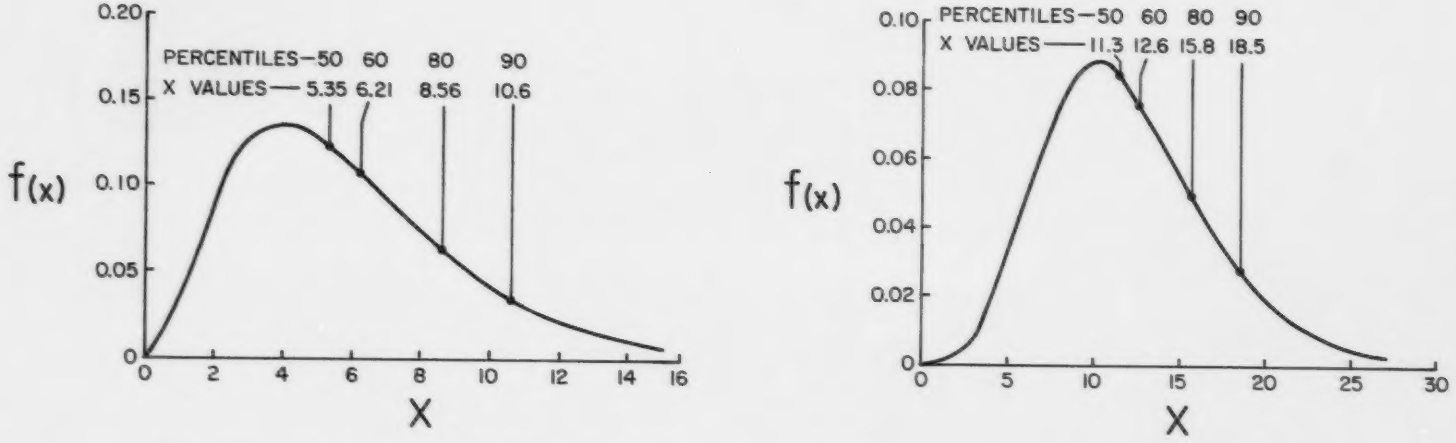
At the 60% CL, the concentric reducer MTBF value is 105,460 hours, which is greater than the point estimate value MTBF of 91,101 hours for the belt drive. However, at the 80% CL, the concentric reducer MTBF value of 76,520 hours is less than the point estimate value MTBF of 91,101 hours for the belt drive.

> Thus, there is a risk of greater than 20% and less than 40% of being wrong if one decides that the true MTBF of the concentric reducer is greater than the point estimate value MTBF of the belt drive power transmission.

The actual significance level for this example is 32.6% as determined by the "F" test method.

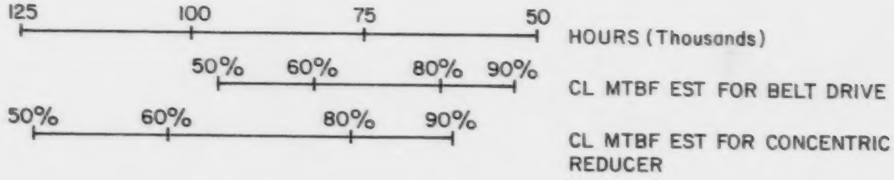
The Chi-Square distributions and the percentiles from which the same calculations could be made are shown in Figure 7, along with a linear graph of the confidence level comparisons. Tables of the appropriate Chi-Square distributions could be used to determine confidence levels for MTBF, using the formula in section 5.4.7.

Figure 6 can also be used for this type of determination for any of the MTBF values presented in the tables of Appendix D, Part 1.0. When the 90% Confidence Limit value MTBF of one equipment type is greater than the point estimate value MTBF of another equipment, there is less than a 10% chance of being wrong in deciding that the first equipment type has a higher MTBF than the second.



(a) CHI-SQUARE DISTRIBUTION WITH 6 DEGREES OF FREEDOM

(b) CHI-SQUARE DISTRIBUTION WITH 12 DEGREES OF FREEDOM



(c) CONFIDENCE LIMIT ON BELT DRIVE AND CONCENTRIC REDUCER

Figure 7.
EXAMPLE OF CHI-SQUARE DISTRIBUTIONS;
PERCENTILES AND CONFIDENCE LIMITS

SECTION 7

COMPARISON OF RELIABILITY DATA FROM WASTEWATER TREATMENT PLANT STUDY TO DATA FROM TWO OTHER SOURCES

A comparison of reliability data from other sources to the reliability data from the Wastewater Treatment Plant Study is useful in assessing how similar components perform in different applications. Two other data sources were identified which contained data on components that were similar in size and/or generic group to those in the Wastewater Treatment Plant Study. These data sources are, "The Non-Electric Parts Reliability Data",(9) "The Nuclear Plant Reliability Data System" (Edison Electric Institute, operated by Southwest Research Institute, San Antonio, TX).(10)

Pertinent performance data were selected from each of the two sources. Mean time between failure (MTBF) calculations were made, using the same methods as were employed for the Wastewater Treatment Plant Study. The results are shown in Table 2.

For most components, there were many more operating hours contained in each of the other two data sources. The wastewater treatment plant MTBF values were lower than for the other two sources, for all the components listed. This could be expected, since the components reported in the Nuclear Plant Reliability Data System are all in the safety class of the nuclear steam supply system. In addition, many of the components from the Non-Electric Parts Reliability Data were qualified to military specifications and were used in military applications. The added safety and/or reliability requirements for components in these types of applications may have contributed to the higher MTBF values.

Various manufacturers and equipment owners were contacted during the study to solicit reliability/performance data on plant components. These manufacturers indicated they did not calculate these statistics.

TABLE 2. COMPARISON OF MTBF FOR COMPONENTS FROM THREE DATA SOURCES

	Data Source											
	Wastewater Treatment Plant				Nuclear Plant Reliability Data System				Reliability Analysis Center			
Component Type	Operating Hours ($x10^6$)	Number of Failures	MTBF ($x10^6$)	90% CL ($x10^6$)	Operating Hours ($x10^6$)	Number of Failures	MTBF ($x10^6$)	90% CL ($x10^6$)	Operating Hours ($x10^6$)	Number of Failures	MTBF ($x10^6$)	90% CL ($x10^6$)
Pumps, Centrifugal	2.11746	97	.021662	.019105	14.134	314	.04491	.03985	5.176	36	.14123	.1150
Pumps, Axial	1.75462	23	.074191	.057623	.454	1	.27023	.11671	--	--	--	--
Power Transmission	11.10382	311	.03562	.03317	4.124	58	.07020	.05379	37.480	303	.12339	.10563
Motors, Multiphase AC	12.4947	183	.0680	.0620	29.050	112	.2576	.2292	7.288	9	.7552	.5132
Motors, Internal Combustion	.03976	1	.02380	.01023	3.523	102	.03429	.03033	--	--	--	--
Compressors - Centrifugal												
Single Stage	.12666	5	.02242	.01369	3.255	18	.17453	.1315	--	--	--	--
Multi-Stage	.54354	96	.005618	.004952	3.896	22	.17201	.13297	--	--	--	--
Valves												
Ball	.01916	1	.01146	.004927	.1340	1	.0798	.0344	11.192	10	1.084	.7268
Butterfly	.05475	1	.03259	.01408	32.1290	62	.5040	.4319	13.675	18	.7332	.5525
Gate	.10402	11	.00893	.00627	5.2140	26	.1956	.1540	7.484	10	.7027	.4860
Plug	.01916	0	.02852	.00832	1.2880	8	.1489	.09908	5.806	19	.2955	.2242

SECTION 8

PERFORMANCE STATISTICS UTILIZATION

There are a variety of uses for the reliability, maintainability and availability statistics presented in Section 6. For example, design engineers can utilize these data as an additional tool to be used for the selection of equipment, determination of the reliability and availability of unit operations as well as entire treatment systems, and the prediction of operational performance of equipment in various applications. Plant owners/operators can utilize preventative and corrective maintenance data to help refine overall future maintenance budget and staffing projections. Knowledge of equipment failure rates and subcomponent failures can provide input into determining spare parts inventories. The following problems and their solutions are presented to demonstrate how inservice performance statistics can be used in these ways.

AVAILABILITY ESTIMATION

Problem: Determine the expected availability of an existing wastewater pumping station.

Given:		
	Peak demand	150,000 gpm
	Existing pumps	3 at 55,000 gpm each
	MTBF of each pump	7500 hours
	MTTR of each pump	100 hours

Solution:

Derive the system event tree state-capacity matrix.

Determine the availability versus capacity for each set of states.

Availability (A) for each pump

$$A = \frac{\text{MTBF}}{\text{MTBF+MTTR}} = \frac{7500}{7500+100} = .9868421053$$

A system event tree is developed showing each operating state, pumping capacity at each state, and the percent of the peak demand flow that can be handled at each state. A_1, A_2 and A_3 define each pump availability. $\overline{A}_1$, $\overline{A}_2$ and $\overline{A}_3$ indicate the pump is unavailable or out of service.

System Event Tree

Operating State	Capacity	% of Peak
$\overline{A}_1\overline{A}_2\overline{A}_3$	0	0
$\overline{A}_1\overline{A}_2A_3$	55,000 gpm	36.67
$\overline{A}_1A_2\overline{A}_3$	55,000 gpm	36.67
$A_1\overline{A}_2\overline{A}_3$	55,000 gpm	36.67
$A_1A_2\overline{A}_3$	110,000 gpm	73.33
$A_1\overline{A}_2A_3$	110,000 gpm	73.33
$\overline{A}_1A_2A_3$	110,000 gpm	73.33
$A_1A_2A_3$	165,000 gpm	110.0

There are 4 capacity states. The percentage of the operating time that the system is in each state can be found using the binomial distribution(7) since:

$$A_1 = A_2 = A_3 \text{ and } \overline{A}_1 = \overline{A}_2 = \overline{A}_3 = 1 - A$$

Let $R = A$ and $Q = \overline{A}$, then

$$(R + Q)^3 = \genfrac{}{}{0pt}{}{3}{0} R^3Q^0 + \genfrac{}{}{0pt}{}{3}{1} R^2Q^1 + \genfrac{}{}{0pt}{}{3}{2} R^1Q^2 + \genfrac{}{}{0pt}{}{3}{3} R^0Q^3$$

$$= R^3 + 3R^2Q + 3RQ^2 + Q^3$$

Replacing R by A and Q by $\overline{A}$ and evaluating the binominal expansion yields the state versus time proportion matrix shown below, for each term yields the proportion of the time that the system will be in the respective state. The state capacity is obtained by multiplying the number of available pumps by the pump capacity.

The state-time proportion matrix is shown below.

State	Time Proportion
165,000 gpm	.9610434283
110,000 gpm	.0384417371
55,000 gpm	.0005125565
0	.0000022781

Thus, in a one year period, on the average, the number of hours in each state would be:

State	Hours per Year
165,000 gpm	8418.740432
110,000 gpm	336.749617
55,000 gpm	4.48999494
0	.019956156

The number of hours in one year is 8760. Therefore, the estimated number of hours per year that this pump station could not be expected to pump at a combined rate of 165,000 gpm would be 8760 - 8419 or 341 hours (14.2 days).

Problem

Determine the state capacity matrix versus probability for the pumping station described in the previous problem with an added pump of 55,000 gpm capacity.

Solution:

The binomial equation for the capacity-probability states is:

$$\binom{4}{0} A^4 \overline{A}^0 + \binom{4}{1} A^3 \overline{A}^1 + \binom{4}{2} A^2 \overline{A}^2 + \binom{4}{3} A^1 \overline{A}^3 + \binom{4}{4} A^0 \overline{A}^4 = 1$$

where

The first term capacity is 4(55,000) = 220,000 gpm

The second term capacity is 3(55,000) = 165,000 gpm

The third term capacity is 2(55,000) = 110,000 gpm

The fourth term capacity is 1(55,000) = 55,000 gpm

The fifth term capacity is 0(55,000) = 0

The matrix below is calculated using the individual pump availability (A) of .9868421053.

State	Time Proportion	Hours per Year
220,000 gpm	.9483981201	8307.967532
165,000 gpm	.0505812331	443.0916017
110,000 gpm	.0010116247	8.861832034
55,000 gpm	.0000089922	.078771672
0 gpm	.0000000299	.000261924

Thus, the addition of a pump has reduced the time that station would be expected to be below the peak demand capability from 341 hours to 8760 - (8308+443) or 9 hours.

There are existing analytical methods(7) to determine the effect of adding new equipment to any existing unit operation, i.e., primary and secondary clarification, aeration, etc. These methods are also useful for determining reliability and availability of the entire treatment plant system. By having access to appropriate performance statistics, designers and operators can develop reliabilities and availabilities for treatment plant designs comprising various types of equipment and identify the design which appears to offer the lowest life cycle cost. This approach to design and equipment component evaluation has been practiced in the electrical and electronics industry since the early 1950's. At the present time, approximately 50 percent of the nuclear power plants in the U.S. participate in a reliability, maintainability and availability data base program. Since Three Mile Island, the industry has begun to evaluate this data base to determine how these data can help prevent similar system failures.

MAINTENANCE COST ESTIMATION

Problem:

Estimate the average maintenance costs for the raw wastewater pumps (excluding motors) in the previous example.

Given:

Number of pumps	3 at 55,000 gpm
Preventative Maintenance (PM)/ Unit/Year	10 manhours
Corrective Maintenance (CM)/ Unit/Year	20 manhours
Labor Costs (average)	$15/hour

Solution:

PM hours/yr = (3 units) 10 manhours/unit/yr
= 30 hours/yr

CM hours/yr = (3 units) 20 manhours/unit/yr
= 60 hours/yr

PM and CM Cost/yr = ($15/hr) 90 hrs/yr
= $1350/yr, or $450/pump/yr

These estimates could be made for all equipment at a planned or existing treatment plant. The results form a base to which the design engineer or owner may apply his own experience, to estimate maintenance costs and staff levels.

SPARE PARTS ESTIMATION

Problem:

Determine the replacement rate for those subcomponents failing most frequently, using the pumps included in the previous example.

Given:

No. of pumps	3 at 55,000 gpm each
MTBF	81,635 hours

Solution:

The failure rate for each pump is

$$\text{Failure rate} = \frac{1}{\text{MTBF}}$$

$$= \frac{1}{81{,}635 \text{ hours}}$$

$$= 1.23\times10^{-5} \text{ failures/hr/pump}$$

For three pumps, the expected number of failures/yr are

$$\frac{\text{No. of failures}}{\text{year}} = 3(1.23\times10^{-5})\ 8760$$

$$= 3.23\times10^{-1} \text{ failures/yr}$$

The distribution of subcomponent failures from the tables in Appendix D, Part 2.0 are

Impeller wear ring	19.7%
Seal, packing, oil lubricated	18.4%
Bearings, ball, double row	7.9%

The parts needed per year are

$$\text{Impeller wear rings/yr} = (.197)3.23\times10^{-1}$$

$$= 0.1$$

$$\text{Seals, packing/yr} = (.184)3.23\times10^{-1}$$

$$= 0.1$$

$$\text{Bearings/yr} = (.079)3.23\times10^{-1}$$

$$= 0.03$$

Thus, an impeller wear ring and packing should require replacement approximately every ten years. A pump bearing should require replacement only every thirty-three years, due to random failure between scheduled preventative maintenance activity.

These are point estimates of the parts needed per year. Confidence intervals can be placed around this point estimate using the Poisson distribution.(7) The Poisson distribution can also be used to determine the number of spares required for a 90% confidence level of having a spare when needed.

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APPENDIX A
DATA NUMBERING SYSTEM

COLUMN 1 (6 Digits)	PLANT AND RECORD NUMBER
First 2 digits plant ID Number	Last 4 digits component record number
COLUMN 2 (2 Digits)	TYPE PLANT
00	No information
01	Air Activated Sludge
02	Oxygen Activated Sludge
03	Trickling Filter
04	Rotating Biological Contractor
05	Combination Air/Oxygen Activated Sludge
COLUMN 3 (2 Digits)	PLANT UNIT OPERATIONS
00	No information
01	Head Works
02	Primary Settling
03	Secondary Treatment (biological unit)
04	Final Settling
05	Disinfection
06	Sludge Processing outside the Waste Treatment Process
07	Anaerobic Digestion
08	Aerobic Digestion
09	Heat Treatment
10	Incineration
11	Sludge Thickening Gravity
12	Sludge Thickening DAF
13	Centrifuge, Solid Bowl
14	Centrifuge, Basket
15	Centrifuge, Nozzle
16	Vacuum Filter
17	Belt Press
COLUMN 4 (2 Digits)	BROAD CLASSIFICATION OF MECHANICAL COMPONENTS
00	No information
01	Pumps (without motor)
02	Power Transmission
03	Motors
04	Compressors
05	Diffusers air/water
06	Valves
07	Controls
08	Pressure Vessels
09	Conveyor (unconfined materials handling)

COLUMN 5 (4 Digits)	GENERIC GROUPS
Pumps	
0000	No information
0100	No information
0101	Self-priming Centrifugal Pump
0102	Submersible Centrifugal
0103	Screw Pump
0104	Progessing Cavity
0105	Diaphragm
0106	Piston
0107	Gear
0108	Air Operated
0109	Open Impeller Centrifugal
0110	Closed Impeller Centrifugal
0111	Open Impeller Centrifugal Close Coupled
0112	Closed Impeller Centrifugal Close Coupled
0113	Pump with Integral Motor
0114	Propeller Pumps, Axial Flow
Power Transmission	
0200	No information
0201	Concentric Reducer
0202	Parallel Shaft
0203	Right-angle Shaft
0204	Vertical Shaft
0205	Variable Speed Drive Belt Type
0206	Variable Speed Drive Hydraulic
0207	Variable Speed Drive Other
0208	Gear Box
0209	Chain Drive
0210	Cyclo Drive (Wemco Sells)
0211	Belt Drive
0212	Flexible Coupling
Motors	
0300	No information
0301	Single Phase
0302	Multi Phase
0303	Air Drive
0304	Hydraulic Drive
0305	Variable Speed, A.C.
0306	Variable Speed, D.C.
0307	D.C. Exciter
0308	Gas Engine

Compressors

0400	No information
0401	Single Stage Centrifugal
0402	Multi Stage Centrifugal
0403	Rotary, Lobe
0404	Rotary Vane
0405	Rotary Water Seal Ring
0406	Multi Stage High Pressure

Diffusers, air/water

0500	No information
0501	Spargers, Large Bubble, Mechanical
0502	Small Bubble Ceramic
0503	Small Bubble Plastic
0504	Small Bubble Mechanical
0505	Static Tube
0506	Circular (for mechanical aerators)
0507	RBC Shaft
0508	Waste to media

Valves

0600	No information
0601	Gate
0602	Ball
0603	Butterfly
0604	Globe
0605	Needle
0606	Relief (safety)
0607	Check
0608	Sluice Gate
0609	Plug

Controls

0700	No information
0701	Electrical
0702	Mechanical
0703	Pressure (fluid)
0704	Pressure (air)
0705	Chlorinators

Pressure Vessels

0800	No information
0801	Chemical Containers
0802	Reactors

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

Conveyor (Unconfined materials handling)

0900	No information
0901	Belt
0902	Screw
0903	Pneumatic
0904	Bucket
0905	Chain (Bar Screen)
0906	Skimmer
0907	Sludge Collector (includes cross collector)

COLUMN 6 (2 Digits)	APPLICATIONS
Headworks	
00	No information
01	Flow Measurement
02	Raw Wastewater Pumping
03	Intermediate Wastewater Pumping
04	Screening/Communition
05	Grit Removal
Primary and Secondary Settling	
06	Clarifier Circular Center Drive
07	Clarifier Circular Peripheral Drive
08	Clarifier Square/Rectangular Center Drive
09	Clarifier Square/Rectangular Peripheral Drive
10	Scum and Grease Removal
Secondary Treatment	(Biological)
11	Return Activated Sludge Handling
12	Recirculation Pumping
13	Oxygen Generation/Storage
14	Dissolved Air Production
15	Dissolved Air/O Application
16	Trickling Filter Rotary Distributor
17	Dosing Siphon
18	Trickling Filter Fixed Distributor
19	Rotating Biological Contactor
20	Mechanical Aerators

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APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

Sludge Handling	
30	Primary Sludge Pumping
31	Secondary Sludge Pumping
32	Waste Activated Sludge Pumping
33	Other Sludge Pumping
34	Digester Gas Recirculation Pumping
Disinfection	
50	Chlorine, Gaseous
51	Chlorine, Hypo
52	Other, O_3, UV, Br_2
Mechanical Mixers	
61	High Speed Fixed
62	Low Speed Fixed
63	High Speed Floating
64	Low Speed Floating
65	Submerged Turbine
66	Fixed Rotor

COLUMN 7 (2 Digits)	SIZE (CAPACITY)
00	No information
01	0-10,000 gallons per minute
02	10,001-20,000 gallons per minute
03	20,001-100,000 gallons per minute
04	Over 100,000 gallons per minute
05	0-1 horsepower
06	2-5 horsepower
07	6-25 horsepower
08	26-100 horsepower
09	101-500 horsepower
10	Over 500 horsepower
11	0-10 cfm
12	11-20 cfm
13	20-25 cfm
14	26-100 cfm
15	101-1000 cfm
16	1001-10,000 cfm
17	10,001-20,000 cfm
18	Over 20,000 cfm
19	0-6″
20	7-12″
21	13-24″
22	25-48″
23	Over 48″
24	Under 2000 lbs chemical
25	Over 2000 lbs chemical

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 8 (3 Digits)	SUBCOMPONENT
000	No information
001	Pump Impeller
002	Impeller Wear Ring or Plate
003	Shaft Sleeve
004	Shaft, Drive
005	Shaft Key
006	Seal, Single Mechanical
007	Seal, Double Mechanical
008	Seal, Packed, No Lubricated
009	Seal, Packed, Water, Oil, Grease Lubricated
010	Seal, Other
011	Coupling
012	Drive Belt
013	Pulley, Belt Drive
014	Bearing Ball, Single Row
015	Experimental/Prototype Bearing
023	Bearing, Ball, Double Row
024	Bearing, Thrust
025	Bearing, Needle
026	Bearing, Cast, Pillow
027	Chain, Pintle
028	Gear for Chain Drive
029	Gear, Worm
030	Gear, Spur
031	Gear, Rack
032	Gear, Pinion
033	Gear, Internal
034	Gear, Miter
035	Gear, Bevel
036	Gear, Helical
037	Magnetic Starter
038	Relay
039	Overload Relay
040	Electrical Timer
041	Switch, Electric
042	Motor Armature
043	Motor Windings
044	Case, Motor
045	Case, Pump
046	Case, Gear
047	Case, Blower
048	Case, Electric or Control Device
049	Controller
050	Brushes
051	Cylinder, Piston Pump

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 8 (3 Digits)	SUBCOMPONENT (Con'td)
052	Collector Mechanism
053	Conveyor Belt
054	Skimmer
055	Solenoid Valve
056	Control Valve
057	Shear Pin
058	Rake Guides
059	Cables
060	Tie Rod
061	End Gate
062	Complete Bearing Replacement
063	Replace Piston
064	Plastic Chain and Flights
065	Pipe Broken
COLUMN 9 (2 Digits)	CRITICALITY
00	No information
01	Effluent impact within 4 hours
02	Effluent impact from 4 to 12 hours
03	Effluent impact from 12 to 24 hours
04	Effluent impact after more than 24 hours
COLUMN 10 (4 Digits)	DATE INSTALLED Month and Year (1072)
COLUMN 11 (2 Digits)	ACTUAL PERCENT OF TIME OPERATING Record actual percentage
COLUMN 12 (2 Digits)	FAILURES
00	No information
99	No failures
01	One fialure
02	Two failures
03	Three failures
04	
05	
COLUMN 13	FAILURE MODE
00	No information

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 14 (2 Digits)	CONTRIBUTORY CAUSE OF FAILURE
00	No information
01	Automatic Lubrication System Failure
02	Misalignment
03	Mechanical Seals
04	Packing Failure/Improper Installation
05	Overload Protection Failure
06	Control System
07	Corrective Maintenance Inadequate or Incomplete
08	Normal Wear
09	Climatic Conditions
10	Unsuitable for Environment
11	Improper Application
12	Preventative Maintenance Inadequate
13	Bad Part
14	Improper Protection from Environment
15	Swapout of Parts trying to cure a problem

COLUMN 15 (2 Digits)	CALENDAR DOWN TIME OF FUNCTION
00	No information
01	1 hour or less
02	1 to 6 hours
03	6 to 24 hours
04	24 to 168 hours
05	Over 168 to 720 hours
06	Over 720 to 4320 hours

COLUMN 16 (2 Digits)	MANHOURS TO REPAIR
00	No information
01	0 to 1 hour
02	Over 1 to 6 hours
03	Over 6 hours to 24 hours
04	Over 24 to 168 hours

*Where more than one failure is shown, times to repair are averaged

COLUMN 17 (2 Digits)	ENVIRONMENTAL FACTOR
00	No information
01	Outdoors, Ambient
02	Outdoors, Heaters
03	Basement, Humid
04	Basement, Dry
05	Subject to Corrosive Splash
06	Subject to Splash

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 17 (2 Digits)	ENVIRONMENTAL FACTOR (Cont'd)
07	Submerged in Water or Sewage
08	Corrosive Atmosphere
09	Submerged in Corrosive Fluid
10	Subject to Freezing
11	Subject to Excessive Heat
12	Indoor Controlled

COLUMN 18 (2 Digits)	PART DISPOSITION
00	No information
01	Repaired in Place
02	Replaced
03	Replaced and Discarded
04	Sent out for Repair

COLUMN 19 (3 Digits)	SUBCOMPONENT MANUFACTURER
000	No information
001	New Departure
002	Hyatt
003	Fafnir
004	Norma Hoffman
005	Falk
006	Fast
007	Thomas
008	John Crane
009	U. S. Varidrive
010	Reeves Varidrive
011	GE Teledyne
012	Dodge
013	Link Belt
014	Rex
015	Dorr Oliver
016	GE
017	Bristol
018	Roots
019	U.S. Electric
020	Marlow
021	Falk
022	Westinghouse
023	Electric Machinery
024	Climax
025	Ideal

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 20 (3 Digits)	COMPONENT MANUFACTURER
000	No information
001	Gorman Rupp
002	PACO
003	HydroMatic
004	Crown
005	Fairbanks Morse
006	Allis Chalmers
007	Worthington
008	GE
009	Roots
010	Door Oliver
011	Komlinc Sanderson
012	U.S. Electric
013	Marlow
014	Hoffman
015	Chicago Pump Co.
016	Marathon Elec.
017	Falk
018	Westinghouse
019	Envirex
020	Dodge
021	Reliance
022	WEMCO
023	FMC
024	Lightnin
025	Clark
026	DeLaval
027	Midland
028	Eimco Envirotech
029	Ralph B. Carter Co.
030	Louis Allis
031	Electric Machinery
032	Wallace and Tiernan Division
033	Autotrol
034	Climax
035	Ideal
036	Fischer and Porter

COLUMN 21 (2 Digits)	INVENTORY INFORMATION
00	No information
01	Stocked at Plant
02	Available Locally (1 to 6 hours)
03	Available within 24 hours
04	Over 24 hours

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 22 (2 Digits)	TYPE OF MAINTENANCE
00	No information
01	Preventative Maintenance
02	Corrective Maintenance
COLUMN 23 (5 Digits)	ACTUAL DOWN TIME OF UNIT OP (Sludge Processing Only)
	Record actual time in hours
COLUMN 24 (4 Digits)	COLLECTION OR DECOMMISSIONING DATE
	First 2 digits are month Second 2 digits are year
COLUMN 25 (4 Digits)	ACTUAL ACTIVE CLOCK TIME TO REPAIR
	Record the sum of the clock time (in hours) when someone worked on unit.

APPENDIX B
RESULTS OF CRITICALITY ANALYSIS

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 1. CRITICALITY ANALYSIS

Type Plant — Air Activated Sludge 01
Unit Operation — Headworks 01

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	02	A	1
	03	A	1
	05	C	
Power Transmission 02	02	A	1
	03	A	1
	05	C	
	04	C	
Motors 03	02	A	1
	03	A	1
	05	C	
	04	C	
Valves 06	01	C	
	02	B	4
	03	B	4
	05	C	
Controls 07	01	C	
	02	B	1
	03	B	1
	04	C	
	05	C	
Conveyors 09	05	C	

TABLE 2. CRITICALITY ANALYSIS

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

Type Plant — Trickling Filter 03
Unit Operation — Headworks 01

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	02	A	1
	03	A	1
	05	C	
Motors 03	02	A	1
	04	C	
	05	C	
	03	A	1
Power Transmission 02	02	A	1
	04	C	
	05	C	
	03	A	1
Conveyor 09	04	C	
	05	C	
Controls 07	01	C	
	02	B	1
	03	B	1
	04	C	
	05	C	
Valves 06	02	B	1
	03	B	1
	05	C	
	01	C	

TABLE 3. CRITICALITY ANALYSIS

Type Plant — Rotating Biological Contractor 04
Unit Operation — Headworks 01

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	02	A	1
	03	A	1
	05	C	
Power Transmission 02	02	A	1
	03	A	1
	04	C	
	05	C	
Motors 03	02	A	1
	03	A	1
	04	C	
	05	C	
Conveyor 09	04	C	
	05	C	
Controls 07	01	C	
	02	B	1
	03	B	1
	04	C	
	05	C	
Valves 06	02	B	4
	03	B	4
	05	C	
	01	C	

TABLE 4. CRITICALITY ANALYSIS

Type Plant — Air Activated Sludge 01
Unit Operation — Primary Settling 02

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	22	B	3
	10	C	
Motors 03	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3
Power Transmission 02	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3
Valves 06	10	C	
	22	B	4
Controls 07	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 5. CRITICALITY ANALYSIS

Type Plant—OAS 02
Unit Operation—Primary Settling 02

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Power Transmission 02	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3
Motors 03	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3
Valves 06	10	C	
	22	B	4
Pumps 01	10	C	
	22	B	3
Controls 07	22	B	3
	10	C	
	06	B	3
	07	B	3
	08	B	3
	09	B	3

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 6. CRITICALITY ANALYSIS

Type Plant—Trickling Filter 03
Unit Operation—Primary Settling 02

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3
Pumps 01	10	C	
	22	A	3
Power Transmission 02	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3
Valves 06	10	C	
	22	B	4
Controls 07	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 7. CRITICALITY ANALYSIS

Type Plant—RBC 04
Unit Operation—Primary Settling 02

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	10	C	
	22	A	3
Motors 03	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3
Power Transmission 02	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3
Valves 06	10	C	
	22	B	4
Controls 07	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 8. CRITICALITY ANALYSIS

Type Plant—Air Act Sludge 01
Unit Operation—Secondary Treatment 03

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	11	A	1
Power Transmission 02	11	A	1
	14 (blower)	A	2
	20	A	2
Motors 03	11	A	1
	14 (blower)	A	2
	20	A	2
Compressors 04	14	A	2
	20	A	2
Diffusers 05	15	A (Subm Turbine)	2
Valves 06	11	B	4
	14	A	2
	15	A	2
Controls 07	11	A	1
	14	A	2
	15	A	2
	20	A	2

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 9. CRITICALITY ANALYSIS

Type Plant—O_2AS 02
Unit Operation—Secondary Treatment 03

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	13	A	2
	15	A	2
	12 Recir. O	A	2
	20	A	2
	11	A	1
Power Transmission 02	13	A	2
	15	A	2
	12	A	2
	20	A	2
	11	A	1
Pumps 01	11	A	1
	12	A	2
Diffusers 05	15	A (Subm Turbine)	2
Pressure Vessels 08	13	B	4
Controls 07	11	A	1
	12	B	4
	13	A	2
	15	A	2
	20	A	2
Valves 06	11	B	4
	13	A	2
	15	A	2

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 10. CRITICALITY ANALYSIS

Type Plant—Trickling Filter 03
Unit Operation—Secondary Treatment 03

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	A	1
Power Transmission 02	12	A	1
Motors 03	12	A	1
Valves 06	12	B	3
Controls 07	12	A	3
	17	B	1
Diffusers 05	16 (Actual Arm)	A	2
	17	A	2
	18	A	2

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Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 11. CRITICALITY ANALYSIS

Type Plant—RBC 04
Unit Operation—Secondary Treatment 03

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	A	1
Power Transmission 02	12	A	1
	19	A	2
	14	A	2
Motors 03	12	A	1
	19	A	2
	14	A	2
Compressors 04	14	A	2
Diffusers 05	19	C	
Valves 06	12	B	3
	14	B	4
Controls 07	12	B	4
	19	A	2
	14	B	4

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 12. CRITICALITY ANALYSIS

Type Plant—Air Act Sludge 01
Unit Operation—Final Settling 04

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Power Transmission 02	06	A	1
	07	A	1
	08	A	1
	09	A	1
Motors 03	06	A	1
	07	A	1
	08	A	1
	09	A	1
Controls 07	06	B	1
	07	B	1
	08	B	1
	09	B	1

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Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 13. CRITICALITY ANALYSIS

Type Plant—O_2AS 02
Unit Operation—Final Settling 04

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	06	A	1
	07	A	1
	08	A	1
	09	A	1
Power Transmission 02	06	A	1
	07	A	1
	08	A	1
	09	A	1
Controls 07	06	B	1
	07	B	1
	08	B	1
	09	B	1

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 14. CRITICALITY ANALYSIS

Type Plant—Trickling Filter 03
Unit Operation—Final Settling 04

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	06	A	1
	07	A	1
	08	A	1
	09	A	1
Power Transmission 02	06	A	1
	07	A	1
	08	A	1
	09	A	1
Controls 07	06	B	1
	07	B	1
	08	B	1
	09	B	1

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Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 15. CRITICALITY ANALYSIS

Type Plant—RBC 04
Unit Operation—Final Settling 04

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	06	A	1
	07	A	1
	08	A	1
	09	A	1
Power Transmission 02	06	A	1
	07	A	1
	08	A	1
	09	A	1
Controls 07	06	B	1
	07	B	1
	08	B	1
	09	B	1

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TABLE 16. CRITICALITY ANALYSIS

Type Plant—Air Act Sludge 01
Unit Operation—Disinfection 06

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	B	1
	50	B	1
	51	B	1
	52	B	1
Motors 03	12	B	1
	50	B	1
	51	B	1
	52	B	1
Diffusers 05	50	C	
	51		
	52		
Valves 06	50	B	4
	51	B	4
	52	B	4
	12	B	4
Controls 07	50	B	4
	51	B	4
	52	B	4
	12	B	4
Power Transmission 02	50	B	1
	52	B	1
	51	B	1
	12	B	1
Pressure Vessels 08	50	B	1
	52	B	1

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 17. CRITICALITY ANALYSIS

Type Plant—O_2AS 02
Unit Operation—Disinfection 06

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	B	1
	50	B	1
	51	B	1
	52	B	1
Motors 03	12	B	1
	50	B	1
	51	B	1
	52	B	1
Diffusers 05	50	C	
	51	C	
	52	C	
Valves 06	50	B	4
	51	B	4
	52	B	4
	12	B	4
Controls 07	50	B	4
	51	B	4
	52	B	4
	12	B	4
Power Transmission 02	50	B	1
	51	B	1
	52	B	1
	12	B	1
Pressure Vessels 08	50	B	1
	52	B	1

TABLE 18. CRITICALITY ANALYSIS

Type Plant—Trickling Filter 03
Unit Operation—Disinfection 06

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	B	1
	50	B	1
	51	B	1
	52	B	1
Motors 03	12	B	1
	50	B	1
	51	B	1
	52	B	1
Diffusers 05	50	C	
	51		
	52		
Valves 06	50	B	4
	51	B	4
	52	B	4
	12	B	4
Controls 07	50	B	4
	51	B	4
	52	B	4
	12	B	4
Power Transmission 02	50	B	1
	52	B	1
	51	B	1
	12	B	1
Pressure Vessels 08	50	B	1
	52	B	1

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 19. CRITICALITY ANALYSIS

Type Plant—RBC 04
Unit Operation—Disinfection 06

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	B	1
	50	B	1
	51	B	1
	52	B	1
Motors 03	12	B	1
	50	B	1
	51	B	1
	52	B	
Diffusers 05	50	C	
	51		
	52		
Valves 06	50	B	4
	51	B	4
	52	B	4
	12	B	4
Controls 07	50	B	4
	51	B	4
	52	B	4
	12	B	4
Power Transmission 02	50	B	1
	51	B	1
	52	B	1
	12	B	1
Pressure Vessels 08	50	B	1
	52	B	1

APPENDIX C
MECHANICAL EQUIPMENT PRIORITY RANKING
TABLE 1. MECHANICAL EQUIPMENT PRIORITY RANKING

Plant Type	Unit Operation	Broad Classification of Equipment	Application	Time and Effect Relationship
01	01	01	02	A1
01	01	01	03	A1
01	01	02	02	A1
01	01	02	03	A1
01	01	03	02	A1
01	01	03	03	A1
02	01	01	02	A1
02	01	01	03	A1
02	01	03	02	A1
02	01	03	03	A1
02	01	02	02	A1
02	01	02	03	A1
03	01	01	02	A1
03	01	01	03	A1
03	01	03	02	A1
03	01	03	03	A1
03	01	02	02	A1
03	01	02	03	A1
04	01	01	02	A1
04	01	01	03	A1
04	01	02	02	A1
04	01	02	03	A1
04	01	03	02	A1
04	01	03	03	A1
01	03	01	11	A1
01	03	02	11	A1
01	03	03	11	A1
02	03	03	11	A1
02	03	02	11	A1
02	03	01	11	A1
03	03	01	12	A1
03	03	02	12	A1
03	03	03	12	A1
04	03	01	12	A1
04	03	02	12	A1
04	03	03	12	A1
01	04	02	06	A1
01	04	02	07	A1
01	04	02	08	A1
01	04	02	09	A1
01	04	03	06	A1
01	04	03	07	A1
01	04	03	08	A1
01	04	03	09	A1
02	04	02	06	A1
02	04	02	07	A1

TABLE 1. MECHANICAL EQUIPMENT PRIORITY RANKING (Cont'd)

Plant Type	Unit Operation	Broad Classification of Equipment	Application	Time and Effect Relationship
02	04	02	08	A1
02	04	02	09	A1
02	04	03	06	A1
02	04	03	07	A1
02	04	03	08	A1
02	04	03	09	A1
03	04	02	06	A1
03	04	02	07	A1
03	04	02	08	A1
03	04	02	09	A1
03	04	03	06	A1
03	04	03	07	A1
03	04	03	08	A1
03	04	03	09	A1
04	04	02	06	A1
04	04	02	07	A1
04	04	02	08	A1
04	04	02	09	A1
04	04	03	06	A1
04	04	03	07	A1
04	04	03	08	A1
04	04	03	09	A1
01	03	02	14	A2
01	03	02	20	A2
01	03	03	14	A2
01	03	03	20	A2
01	03	04	14	A2
01	03	04	20	A2
01	03	05	15	A2
01	03	06	14	A2
01	03	06	15	A2
01	03	07	14	A2
01	03	07	15	A2
01	03	07	20	A2
02	03	03	13	A2
			15	A2
			12	A2
			20	A2
02	03	02	13	A2
		02	15	A2
		02	12	A2
		02	20	A2
		01	12	A2
		05	15	A2
		07	13	A2
		07	15	A2

TABLE 1. MECHANICAL EQUIPMENT PRIORITY RANKING (Cont'd)

Plant Type	Unit Operation	Broad Classification of Equipment	Application	Time and Effect Relationship
02	03	07	20	A2
		06	13	A2
		06	15	A2
03	03	05	16	A2
		05	17	A2
		05	18	A2
04	03	02	19	A2
		02	14	A2
		03	19	A2
		03	14	A2
		04	14	A2
		07	19	A2
03	02	03	06	A3
		03	07	A3
		03	08	A3
		03	09	A3
		02	06	A3
		02	07	A3
		02	08	A3
		02	09	A3
		07	06	A3
		07	07	A3
		07	08	A3
		07	09	A3
		03	06	A3
		03	07	A3
		03	08	A3
		03	09	A3
		02	06	A3
		02	07	A3
		02	08	A3
		07	08	A3
		07	09	A3
03	03	07	12	A3
01	01	07	02	B1
			03	B1
02	01	07	03	B1
			03	B1
03	01	07	02	B1
			03	B1
03	01	06	02	B1
			03	B1
04	01	07	02	B1
			03	B1
03	03	07	17	B1
01	04	07	06	B1

TABLE 1. MECHANICAL EQUIPMENT PRIORITY RANKING (Cont'd)

Plant Type	Unit Operation	Broad Classification of Equipment	Application	Time and Effect Relationship
01	04		07	B1
			08	B1
			09	B1
02	04	07	06	B1
			07	B1
			08	B1
			09	B1
03	04	07	06	B1
			08	B1
			09	B1
04	04	07	06	B1
			07	B1
			08	B1
			09	B1
01-02	05	01	12	B1
03-04			50	B1
			51	B1
			52	B1
		03	12	B1
			50	B1
			51	B1
			52	B1
		02	12	B1
			50	B1
			51	B1
			52	B1
01-02	05	08	50	B1
03-04			52	B1
01-02	02	01	22	B3
01-02	02	03	06	B3
			07	B3
			08	B3
			09	B3
			22	B3
01-02	02	02	06	B3
			07	B3
			08	B3
			09	B3
			22	B3
01-02	02	07	06	B3
			07	B3
			08	B3
			09	B3
			22	B3
04	03	06	12	B3

APPENDIX D
SUMMARY OF PERFORMANCE STATISTICS CALCULATED ON CRITICAL COMPONENTS

1.0 Reliability, Maintainability and Availability Statistics for Components

- 1.1 By Component

  - 1.1.1 Reliability (Table 1.1.1)
  - 1.1.2 Maintainability and Availability (Table 1.1.2)

- 1.2 By Component by Generic Group

  - 1.2.1 Reliability (Table 1.2.1)
  - 1.2.2 Maintainability and Availability (Table 1.2.2)

- 1.3 By Component by Application

  - 1.3.1 Reliability (Table 1.3.1)
  - 1.3.2 Maintainability and Availability (Table 1.3.2)

- 1.4 By Component by Size/Capacity

  - 1.4.1 Reliability (Table 1.4.1)
  - 1.4.2 Maintainability and Availability (Table 1.4.2)

- 1.5 By Component by Generic Group by Application

  - 1.5.1 Pumps (Tables 1.5.1.1 and 1.5.1.2)
  - 1.5.2 Power Transmissions (Tables 1.5.2.1 through 1.5.2.9)
  - 1.5.3 Motors (Tables 1.5.3.1 through 1.5.3.4)
  - 1.5.4 Compressors (Tables 1.5.4.1 through 1.5.4.3)
  - 1.5.5 Diffusers, Air/Water (Tables 1.5.5.1 and 1.5.5.2)
  - 1.5.6 Valves (Tables 1.5.6.1 through 1.5.6.4)
  - 1.5.7 Controls (Tables 1.5.7.1 through 1.5.7.5)
  - 1.5.8 Conveyors (Tables 1.5.8.1 and 1.5.8.2)

- 1.6 By Component by Generic Group by Size/Capacity

  - 1.6.1 Pumps (Tables 1.6.1.1 and 1.6.1.2)
  - 1.6.2 Power Transmissions (Tables 1.6.2.1 through 1.6.2.9)
  - 1.6.3 Motors (Tables 1.6.3.1 through 1.6.3.4)
  - 1.6.4 Compressors (Tables 1.6.4.1 through 1.6.4.3)
  - 1.6.5 Diffusers, Air/Water (Tables 1.6.5.1 and 1.6.5.2)
  - 1.6.6 Valves (Tables 1.6.6.1 through 1.6.6.4)
  - 1.6.7 Controls (Tables 1.6.7.1 through 1.6.7.5)
  - 1.6.8 Conveyors (Tables 1.6.8.1 and 1.6.8.2)

2.0 Component Failure Statistics by Subcomponent Type

- 2.1 By Component (Tables 2.1.1 through 2.1.8)
- 2.2 By Component by Generic Group

  - 2.2.1 Pumps (Tables 2.2.1.1 and 2.2.1.2)
  - 2.2.2 Power Transmissions (Tables 2.2.2.1 through 2.2.2.3)

    2.2.3 Motors (Tables 2.2.3.1 through 2.2.3.4)
    2.2.4 Compressors (Tables 2.2.4.1 and 2.2.4.2)
    2.2.5 Diffusers, Air/Water (Table 2.2.5.1)
    2.2.6 Valves (Table 2.2.6.1)
    2.2.7 Controls (Tables 2.2.7.1 through 2.2.7.4)
    2.2.8 Conveyors (Table 2.2.8.1)

  2.3 By Component by Application

    2.3.1 Pumps (Tables 2.3.1.1 through 2.3.1.4)
    2.3.2 Power Transmissions (Tables 2.3.2.1 through 2.3.2.3)
    2.3.3 Motors (Tables 2.3.3.1 through 2.3.3.6)
    2.3.4 Compressors (Tables 2.3.4.1 and 2.3.4.2)
    2.3.5 Diffusers, Air/Water (Table 2.3.5.1)
    2.3.6 Valves (Tables 2.3.6.1 and 2.3.6.2)
    2.3.7 Controls (Tables 2.3.7.1 through 2.3.7.8)
    2.3.8 Conveyors (Table 2.3.8.1)

  2.4 By Component by Size

    2.4.1 Pumps (Tables 2.4.1.1 through 2.4.1.4)
    2.4.2 Power Transmissions (Tables 2.4.2.1 through 2.4.2.5)
    2.4.3 Motors (Tables 2.4.3.1 through 2.4.3.4)
    2.4.4 Compressors (Tables 2.4.4.1 through 2.4.4.3)
    2.4.5 Diffusers, Air/Water (Table 2.4.5.1)
    2.4.6 Valves (Tables 2.4.6.1 and 2.4.6.2)
    2.4.7 Controls (Tables 2.4.7.1 through 2.4.7.5)
    2.4.8 Conveyors (Table 2.4.8.1)

3.0 Reliability and Availability Statistics for Sludge Processes

  3.1 By Sludge Process (Table 3.1.1)

APPENDIX D
PART 1.0
RELIABILITY MAINTAINABILITY AND AVAILABILITY STATISTICS FOR COMPONENTS

TABLE 1.1.1. MEAN TIME BETWEEN FAILURE (MTBF) FOR COMPONENTS

Component	Overall MTBF ($\times 10^6$ Hrs)	Min MTBF ($\times 10^6$ Hrs)	Max MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)
Pumps	.032066	.021662	.074191	.028630
Power transmissions	.03562	.01785	.71091	.03317
Motors	.06670	.01088	.11482	.06122
Compressors	.00714	.00562	.08392	.00631
Diffusers, air/water	.01813	.01263	1.834	.01667
Valves	.01444	.00893	.03259	.01040
Controls	.08358	.00393	.10064	.07569
Conveyor (unconfined materials handling)	.14848	.06175	.35856	.11690

TABLE 1.1.2. MAINTENANCE STATISTICS FOR COMPONENTS

Components	PM-Hrs/ Unit/Yr	CM-Hrs/ Unit/Yr	MTTR (Hrs)	AVI	AVO
Pumps	.00227	.05177	9.541	.99968	.99116
Power transmissions	.00032	.00469	2.273	.99994	.99898
Motors	.00098	.00660	6.854	.99989	.99816
Compressors	.03399	.17843	0.960	.99987	.99306
Diffusers, air/water	.00065	.04664	8.305	.99951	.99875
Valves	.00684	.73845	11.615	.99879	.96446
Controls	.00025	.00261	3.696	.99996	.99870
Conveyer (unconfined materials handling)	.00055	.10086	4.768	.99996	.99980

TABLE 1.2.1. MEAN TIME BETWEEN FAILURES (MTBF) FOR COMPONENTS BY GENERIC GROUP

Component	Generic Group	Overall MTBF (× 10^6 Hrs)	Min MTBF (× 10^6 Hrs)	Max MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)
Pumps	Open impeller, centrifugal	.02166	.01530	.03569	.019105
	Propeller, axial flow	.074191	.02415	.7528	.05762
Power transmission	Concentric reducer	.12264	.02814	.3764	.06190
	Parallel shaft	.71091	.01996	1.867	.35881
	Right angle shaft	.01948	.00993	2.512	.01772
	Vertical shaft	.03147	.01925	.06091	.02611
	Variable speed drive, hydraulic	.3495			.1020
	Variable speed drive, others	.01842	.00784	.02689	.01075
	Gear box	.04578	.00982	.6313	.03932
	Chain drive	.01785			.01091
	Belt drive	.09101			.05564
Motors	Multiphase	.0680	.02102	4.4939	.0620
	Variable speed, AC	.11482	.01081	.4033	.05795
	Gas engine	.02380			.01023
Compressors	Single stage, centrifugal	.02242	.01934	.02173	.01369
	Multi stage, centrifugal	.00562	.00544	.02689	.00495
	Multi stage, high pressure	.08392	.02933	.05459	.02449
Diffusers, air/water	RBC Shaft	1.834			.5352
	Waste to media	.01263			.01160
Valves	Gate	.00893	.00702	.01353	.00627
	Ball	.01146			.00493
	Butterfly	.03259			.01408
	Plug	.02852			.00832
Controls	Electrical	.10064	.01859	4.6849	.08994
	Mechanical	.03123	.01705	.03334	.01282
	Pressure (fluid)	.03578	.03140	.06485	.02676
	Pressure—air	.01869			.01272
	Chlorinators	.00393			.00262
Conveyor (unconfined materials handling)	Chain (bar screen)	.06175			.04688
	Sludge collector	.35856	.2202	1.570	.23345

TABLE 1.2.2. MAINTENANCE STATISTICS FOR COMPONENTS BY GENERIC GROUP

Component	Generic group	PM-Hrs/ Unit/Yr	CM-Hrs/ Unit/Yr	MTTR (Hrs)	AVI	AVO
Pumps	Open impeller centrifugal	.00343	.09477	7.825	.99962	.98955
	Propeller, axial flow	.00627	.11411	16.780	.99975	.99311
Power transmission	Concentric reducer	.01187	.00890	2.000	.99998	.99998
	Parallel shaft	.00224	.01208	32.000	.99995	.99990
	Right angle shaft	.00103	.01244	1.400	.99995	.99989
	Vertical shaft	.00122	.03331	2.023	.99994	.99686
	Variable speed drive, hydraulic	.01865	0.0		1.0	1.0
	Variable speed drive, others	.39460	.61080	2.500	.99976	.99952
	Gear box	.00045	.05956	3.523	.99993	.99952
	Chain drive	0.0	1.3640	8.000	.9996	.9945
	Belt drive	0.0	.08488	1.800	1.0	.9916
Motors	Multiphase	.00068	.00693	6.853	.99989	.99837
	Variable speed, AC	.01258	.05034	8.000	.99996	.99986
	DC exciter	1.62195	1.59810	3.667	.9967	.99035
	Gas engine	10.57	10.57	24.000	.9990	.9342
Compressors	Single stage, centrifugal	.16854	.31990	3.800	.99981	.99541
	Multi stage, centrifugal	.06513	.44723	0.813	.99987	.99179
	Multi stage, high pressure	.07767	0.0		1.0	1.0
Diffusers, air/water	RBC Shaft	.00356	0.0		1.0	1.0
	Waste to media	.00008	.1591	8.305	.9993	.9982
Valves	Gate	0.0	1.40743	3.636	.99947	.95693
	Ball	0.0	43.89	110.000	.905	.8685
	Butterfly	.05999	.12005	1.000	.99997	.99993
	Plug	.2286	0.0		1.0	1.0
Controls	Electrical	.00028	.00211	2.893	.99998	.99922
	Mechanical	.04385	.96717	8.000	.99966	.99839
	Pressure (fluid)	.00405	.12830	8.236	.99975	.98822
	Pressure—air	.00970	.1309	3.556	.9998	.9998
	Chlorinators	0.0	17.82	5.375	.9986	.9982
Conveyor (unconfined materials handling)	Chain (bar screen)	0.0	.1371	0.947	1.0	.9999
	Sludge collector	.00098	.16507	15.14	.99994	.999751

TABLE 1.3.1. MEAN TIME BETWEEN FAILURES (MTBF) FOR COMPONENTS BY APPLICATION

Component	Application	Overall MTBF (× 10^6 Hrs)	Min MTBF (× 10^6 Hrs)	Max MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)
Pumps	Raw Wastewater Pumping	.01530			.01303
	Intermediate Wastewater Pumping	.08588	.01727	.09255	.06318
	Return Activated Sludge Handling	.05336	.7528	.03569	.04235
	Recirculation Pumping	.02415			.01759
Power Transmission	Raw Wastewater Pumping	.01884	.00784	.05919	.01303
	Intermediate Wastewater Pumping	.18861	.02689	.1678	.05679
	Clarifier, Circular Center Drive	.01605	.00993	.09101	.01389
	Clarifier, Square/Rectangular Peripheral	.08044	.00982	2.512	.06760
	Return Activated Sludge Handling	.7037	.3495	.3764	.2118
	Oxygen Generation/Storage	.09389			.02740
	Dissolved Air Production	.1763			.08847
	Rotating Biological Contactors	1.867			.5449
	Mechanical Aerators	.06136	.04735	.06091	.04365
Motors	Raw Wastewater Pumping	.02192	.01163	.02380	.01754
	Intermediate Wastewater Pumping	.06523	.006764	.3931	.04380
	Screening/Communition	1.8100			.5283
	Clarifier, Circular Center Drive	.1236			.09442
	Clarifier, Square/Rectangular Peripheral	4.4935	.5650	2.512	1.356
	Return Activated Sludge Handling	.02642	.01081	.4033	.02214
	Recirculation Pumping	.0531			.03362
	Oxygen Generation/Storage	.08392			.02449
	Dissolved Air Production	.02319	.01858	.02282	.01792
	Dissolved Air/O_2 Application	.01353			.006789
	Rotating Biological Contactor	.02215			.01876
	Mechanical Aerators	.6711			.1959
	Secondary Sludge Pumping	.1513	.0216	.3226	.0650
Compressors	Dissolved Air Production	.00575	.00544	.02173	.005069
	Dissolved Air/O_2 Production	.02321	.01934	.02689	.01172
	Oxygen Generation/Storage	.08392			.02449
Diffusers, Air/Water	Rotating Biological Contactor	1.834			.5352
	Trickling Filter Rotary Distributor	.01263			.01160
Valves	Raw Wastewater Pumping	.00997	.00702	.02852	.00694
	Intermediate Wastewater Pumping	.01353			.00679
	Oxygen Generation/Storage	.05459			.01593
	Dissolved Air/O_2 Production	.01081			.00465
Controls	Raw Wastewater Pumping	.03898	.03334	.03742	.02834
	Intermediate Wastewater Pumping	.14729	.01705	.1907	.09589
	Screening/Communition	1.810			.5288
	Clarifier, Circular Center Drive	.1144	.01081	.1191	.08796
	Clarifier, Square/Rectangular Peripheral	4.609	.5270	2.512	1.345
	Return Activated Sludge Handling	.01859	.00043	.01895	.01578
	Recirculation Pumping	.04618			.03008
	Oxygen Generation/Storage	.08392			.02449
	Dissolved Air Production	.04871			.03315
	Rotating Biological Contactor	1.867			.5449
	Mechanical Aerators	.05620	.01081	.06116	.03748
	Secondary Sludge Pumping	.09866	.06485	.09497	.05404
	Chlorine, Gaseous	.02193	.01869	.03140	.01772
Conveyor (Unconfined Materials Handling)	Screening/Communition	.06175			.04688
	Clarifier, Square/Rectangular Peripheral	.35856	.2202	1.570	.23345

TABLE 1.3.2. MAINTENANCE STATISTICS FOR COMPONENTS BY APPLICATION

Component	Application	PM-Hrs/ Unit/Yr	CM-Hrs/ Unit/Yr	MTTR Hrs	AVI	AVO
Pumps	Raw Wastewater Pumping	.00944	.3178	8.483	.9994	.9845
	Intermediate Wastewater Pumping	.03301	.47335	13.334	.99977	.99087
	Return Activated Sludge Handling	.00232	.03377	6.786	.99987	.99987
	Recirculation Pumping	.00353	.5945	14.710	.9994	.9719
Power Transmission	Raw Wastewater Pumping	.01092	.00198	2.800	.99985	.99977
	Intermediate Wastewater Pumping	.17227	0.0		1.0	.99989
	Clarifier, Circular Center Drive	.00072	.01971	1.775	.99991	.99759
	Clarifier, Square/Rectangular Peripheral	.00058	.03355	2.787	.99998	.99956
	Return Activated Sludge Handling	.00898	0.0		1.0	1.0
	Oxygen Generation/Storage	.06942	0.0		1.0	1.0
	Dissolved Air Production	.00620	.5953	32.000	.9998	.9996
	Rotating Biological Contactors	.00349	0.0		1.0	1.0
	Mechanical Aerators	.00228	.04797	4.833	.9999	.9999
Motors	Raw Wastewater Pumping	.07434	.30876	8.871	.99957	.99061
	Intermediate Wastewater Pumping	.00302	.03782	4.400	.99999	.99980
	Screening/Communition	.00360	0.0		1.0	1.0
	Clarifier, Circular Center Drive	.00957	.01893	2.600	1.0	.9983
	Clarifier, Square/Rectangular Peripheral	.00140	0.0		1.0	.9999
	Return Activated Sludge Handling	.00202	.07879	5.368	.99977	.99943
	Recirculation Pumping	.00795	.2385	12.500	.9998	.9842
	Oxygen Generation/Storage	.07767	0.0		1.0	1.0
	Dissolved Air Production	.0485	.5214	8.455	.9996	.9912
	Dissolved Air/O_2 Production	.06061	.2424	1.000	.9999	.9999
	Rotating Biological Contactor	0.0	.1047	7.857	.9996	.9993
	Mechanical Aerator	.00971	0.0		1.0	1.0
	Secondary Sludge Pumping	.01608	.00742	2.000	1.0	1.0
Compressors	Dissolved Air Production	.07405	.38760	0.887	.99985	.99108
	Dissolved Air/O_2 Production	.02020	.29631	2.750	.99992	.99967
	Oxygen Generation/Storage	.07767	0.0		1.0	1.0
Diffusers, Air/Water	Rotating Biological Contactor	.00356	0.0		1.0	1.0
	Trickling Filter Rotary Distributor	.00008	.1591	8.305	.9993	.9982
Valves	Raw Wastewater Pumping	.00589	2.15610	13.400	.99800	.93513
	Intermediate Wastewater Pumping	0.0	3.6365	4.500	.9993	.99695
	Oxygen Generation/Storage	.1194	0.0		1.0	1.0
	Dissolved Air/O_2 Production	0.0	1.455	1.000	.9999	.9998
Controls	Raw Wastewater Pumping	.00453	.14466	4.643	.99986	.99953
	Intermediate Wastewater Pumping	.00907	.08034	6.571	.99996	.99744
	Screening/Communition	.00360	0.0		1.0	1.0
	Clarifier, Circular Center Drive	.00130	.00580	2.000	.99999	.99999
	Clarifier, Square/Rectangular Peripheral	.00147	0.0		1.0	.99989
	Return Activated Sludge Handling	.00074	.05812	2.607	.99989	.99981
	Recirculation Pumping	.00795	.07951	5.571	.9999	.9845
	Oxygen Generation/Storage	.07767	0.0		1.0	1.0
	Dissolved Air Production	.00155	.1457	1.333	1.0	.9999
	Rotating Biological Contractor	.00349	0.0		1.0	1.0
	Mechanical Aerators	.00069	.03977	1.750	.99998	.99998
	Secondary Sludge Pumping	.01152	.01037	2.667	1.0	.99871
	Chlorine, Gaseous	.00125	.21428	6.425	.99967	.98980
Conveyor (Unconfined Materials Handling)	Screening/Communition	0.0	.1371	0.947	1.0	.9999
	Clarifier, Square/Rectangular Peripheral	.00098	.16507	15.14	.99994	.99975

TABLE 1.4.1. MEAN TIME BETWEEN FAILURES (MTBF) FOR COMPONENTS BY SIZE

Component	Application	Overall MTBF (× 10^6 Hrs)	Min MTBF (× 10^6 Hrs)	Max MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)
Pumps	1-1,000 Gallons Per Minute	.0396	.03569	.1678	.03146
	10,001-20,000	.031130	.01378	.5377	.02442
	20,001-100,000	.081635	.02602	.1838	.061515
	Over 100,000	.008366	.005068	.2151	.007010
Power Transmission	0-1 Horsepower	.02537	.00993	2.5120	.02341
	1-5	.01101	.00982	.01785	.00912
	6-25	1.3764	.6316	1.867	.59387
	26-100	.05862	.03476	.06091	.04176
	101-500	.07838	.00784	.3764	.05420
	Over 500	.20645	.02689	.1763	.10373
Motors	0-1 Horsepower	.2147	.1236	2.512	.1349
	1-5	.5646			.1648
	6-25	.0621	.0222	1.810	.0527
	26-100	.0460	.0210	1.334	.0347
	101-500	.06463	.02380	.4033	.04903
	Over 500	.02058	.01088	.0231	.01685
Compressors	101-1,000 Cubic Feet Per Minute	.05459			.01593
	1,001-10,000	.02744	.01934	.02933	.01602
	10,001-20,000	.01487			.00817
	Over 20,000	.00535	.02173	.00530	.00471
Diffusers, Air/Water	6-25 Horsepower	1.834			.5352
	10,001-20,000 Gallons Per Minute	.01487			.01160
Valves	0-6 Inches	.05459			.01593
	13-24	.01081			.00465
	25-48	.01907	.00812	.02852	.01044
	Over 48	.00750	.00627	.01081	.00510
	Over 48 Inches	.06175			.04688
Controls	0-1 Horsepower	2.0092	.1191	2.512	.15686
	1-5	.50950			.15362
	6-25	4.6849	1.570	1.867	1.41258
	26-100	.026109	.01895	.06116	.02252
	101-500	.09939	.01081	.6144	.07587
	Over 500	.03770	.00434	.08392	.02796
	Over 2000 lbs. Chemical	.02193	.03408	.5232	.01772
Conveyor (Unconfined Materials Handling)	0-1 Horsepower	.2202			.1434
	6-25 Horsepower	1.570			.4583

TABLE 1.4.2. MAINTENANCE STATISTICS FOR COMPONENTS BY SIZE

Component	Application	PM-Hrs/ Unit/Yr	CM-Hrs/ Unit/Yr	MTTR Hrs	AVI	AVO
Pumps	1-1,000 Gallons Per Minute	.00199	.07576	6.786	.99982	.99981
	10,001-20,000	.00349	.17403	7.800	.99974	.99831
	20,001-100,000	.00133	.17748	26.722	.99964	.98925
	Over 100,000	.07379	.83854	9.368	.99931	.96080
Power Transmission	0-1 Horsepower	.00042	.01266	1.815	.99994	.99847
	2-5	.00288	.29455	2.116	.99984	.99789
	6-25	.00187	.00597	25.000	1.0000	.99982
	26-100	.00180	.05849	5.000	.99995	.99989
	101-500	.00490	.00700	2.600	.99996	.99995
	Over 500	.02579	.25385	32.000	.99981	.99959
Motors	0-1 Horsepower	.00522	.01009	2.600	1.0000	.99890
	2-5	.01152	0.0		1.0000	1.0000
	6-25	.00016	.03261	7.857	.99985	.99975
	26-100	.00108	.03098	4.9665	.99987	.99962
	101-500	.01221	.06992	12.685	.99980	.99289
	Over 500	.04174	.20070	7.658	.99959	.98971
Compressors	101-1,000 Cubic Feet Per Minute	.1194	0.0		1.0000	1.0000
	1,001-10,000	.02136	.18805	2.750	.99993	.99972
	10,001-20,000	.03211	1.4450	6.000	.99960	.99930
	Over 20,000	.12567	.58143	0.723	.99988	.99020
Diffusers, Air/Water	6-25 Horsepower	.00356	0.0		1.0000	1.0000
	10,001-20,000 Gallons Per Minute	.00008	.15910	8.305	.9993	.9982
Valves	0-6 Inches	.1194	0.0		1.0	1.0
	13-24	0.0	1.455	1.000	.9999	.9998
	25-48	.01565	3.9437	42.000	.99702	.96357
	Over 48	0.0	2.15075	2.667	.99960	.93850
Controls	0-1 Horsepower	.00083	.00296	2.050	1.0	.99992
	2-5	.01325		0.0	1.0	1.0
	6-25	.00124	0.0		1.0	1.0
	26-100	.00034	.02615	2.377	.99993	.99988
	101-500	.00258	.01876	5.450	.99995	.99692
	Over 500 Horsepower	.00310	.11783	3.125	.99990	.99551
	Over 2000 lbs. Chemical	.00125	.21428	6.425	.99967	.98980
Conveyor (Unconfined Materials Handling)	Over 48 Inches	0.0	.1371	0.947	1.0	.9999
	0-1 Horsepower	.00097	.4359	15.14	.9999	.9996
	6-25 Horsepower	.00415	0.0		1.0	1.0

TABLE 1.5.1.1. RELIABILITY AND MAINTENANCE DATA FOR PUMPS—OPEN IMPELLER CENTRIFUGAL BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs. (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	34	60	.9277	.01530	—	—	.01303	.009442	.3179	8.483	.994	.9845
Intermediate Wastewater Pumping	9	9	.1669	.01727	—	—	.01175	.1079	.7871	6.667	.9996	.9548
Return Activated Sludge Handling	27	28	1.023	.03569	—	—	.02835	.001745	.1028	6.786	.9998	.9998
TOTAL	70	97	2.1176	.02166	.01530	.03569	.01911	.003428	.094773	7.825	.99962	.98955

TABLE 1.5.1.2. RELIABILITY AND MAINTENANCE DATA FOR PUMPS—PROPELLER, AXIAL FLOW BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs. (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Intermediate Wastewater Pumping	7	9	.8947	.09255	—	—	.06298	.06364	1.095	20.00	.9998	.9976
Return Activated Sludge Handling	28	0	.5059	.7528	—	—	.2197	.008658	0.0	—	1.0	1.0
Recirculation Pumping	14	14	.3541	.02415	—	—	.01759	.003534	.5955	14.71	.9994	.9719
TOTAL	49	23	1.7547	.07419	.02415	.7528	.05763	.006265	.1140107	16.783	.99975	.99311

TABLE 1.5.2.1. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION—CONCENTRIC REDUCER BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Circular Center Drive	4	2	.07516	.02814	—	—	.01412	.02914	.1748	2.0	.9999	.9999
Reutrn Activated Sludge Handling	14	0	.2529	.3764	—	—	.1099	.01732	0.0	—	1.0	1.0
TOTAL	18	2	.32806	.12264	.02814	.3764	.061898	.01187	.00890	2.0	.99998	.99998

TABLE 1.5.2.2. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION—PARALLEL SHAFT BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Intermediate Wastewater Pumping	6	0	.1127	.1678	—	—	.04896	.03885	0.0	—	1.0	1.0
Oxygen Generation/ Storage	5	0	.06309	.09389	—	—	.02740	.06942	0.0	—	1.0	1.0
Dissolved Air Production	6	2	.4709	.1763	—	—	.08847	.006201	.5953	32.0	.9998	.9996
Rotating Biological Contactor	56	0	1.255	1.867	—	—	.5449	.003491	0.0	—	1.0	1.0
TOTAL	73	2	1.90169	.71091	.09389	1.867	.35881	.002241	.012075	32.0	.99995	.99990

TABLE 1.5.2.3. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION—RIGHT ANGLE SHAFT BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	2	0	.03978	.05919	—	—	.01728	.1101	0.0	—	1.0	1.0
Clarifier Circular Center Drive	41	180	1.793	.009929	—	—	.009035	.001907	.03039	1.4	.9999	.9998
Clarifier Square/ Rectangular Peripheral	8	0	1.688	2.512	—	—	.7332	.002594	0.0	—	1.0	1.0
TOTAL	51	180	3.52078	.019479	.009929	2.512	.017747	.001025	.01244	1.4	.99995	.99989

TABLE 1.5.2.4. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION—VERTICAL SHAFT BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Circular Center Drive	9	32	.6287	.01925	—	—	.01551	.002322	.1455	.9688	1.0	.9931
Mechanical Aerators	42	12	.7762	.06128	.04735	.06091	.04365	.002284	.04797	4.833	.9999	.9999
TOTAL	51	44	1.4049	.031465	.01925	.06128	.026113	.001223	.03331	2.023	.99994	.99686

TABLE 1.5.2.5. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION—VARIABLE SPEED DRIVE, HYDRAULIC BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Return Activated Sludge Handling	13	0	.2349	.3495	—	—	.1020	.01865	0.0	—	1.0	1.0

TABLE 1.5.2.6. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION—VARIABLE SPEED DRIVE—OTHER BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	3	8	.06796	.007841	—	—	.005230	.02148	1.031	2.5	.9997	.9996
Intermediate Wastewater Pumping	1	0	.01807	.02689	—	—	.007847	—	7.273	0.0	1.0	.9992
TOTAL	4	8	.08603	.018422	.007841	.02689	.010754	.3946	.6108	2.5	.99976	.99952

TABLE 1.5.2.7. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION—GEAR BOX BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	1	2	.09286	.03476	—	—	.01745	.5660	4.0	.9999	.9998	0.0
Clarifier Circular Center Drive	8	21	.8499	.03924	—	—	.03016	.2512	6.19	.9998	.9997	.000921
Clarifier Square/ Rectangular Peripheral	23	42	2.0675	.04848	.000816	.6313	.04008	.0833	2.1666	.999982	.99944	.0004547
TOTAL	32	65	3.1026	.045783	.03476	.04848	.039323	.059560	3.523	.99993	.99952	—

TABLE 1.5.2.8. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION — CHAIN DRIVE BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Square/ Rectangular Peripheral	4	5	.1012	.01785	–	–	.01091	0.0	1.364	8.0	.9996	.9945

TABLE 1.5.2.9. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION — BELT DRIVE BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Circular Center Drive	3	5	.5160	.09101	–	–	.05564	0.0	.08488	1.8	1.0	.9916

TABLE 1.5.3.1. RELIABILITY AND MAINTENANCE DATA FOR MOTORS

Mean Time Between Failures (MTBF) By Application
Broad Classification—Motors
Generic Group—Multiphase

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)
Raw Wastewater Pumping	25	26	.5997	.02249	.00983	.02795	.01772
Intermediate Wastewater Pumping	14	2	1.050	.3931	.0422	1.334	.1973
Screening/Communition	3	0	1.216	1.810	–	–	.5283
Clarifier, Circular Center Drive	62	20	2.553	.1236	–	–	.09442
Clarifier, Square/ Rectangular Peripheral	28	0	3.1224	4.4935	.5650	2.512	1.356
Return Activated Sludge Handling	27	48	1.0227	.02102	–	–	.01759
Recirculation Pumping	14	6	.3541	.0531	–	–	.03362
Oxygen Generation/ Storage	5	0	.00563	.08392	–	–	.02449
Dissolved Air Production	11	22	.5255	.02319	.01858	.02282	.01792
Dissolved Air/O_2 Application	2	2	.0361	.01353	–	–	.006789
Rotating Biological Contactor	56	56	1.255	.02215	–	–	.01876
Mechanical Aerators	24	0	.4510	.6711	–	–	.1959
Secondary Sludge Pumping	14	1	.2529	.1513	.0216	.3226	.0650
TOTAL	285	183	12.4947	.0680	.02102	4.4935	.0620

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TABLE 1.5.3.2. RELIABILITY AND MAINTENANCE DATA FOR MOTORS

Maintenance Statistics By Application
Broad Classification — Motors
Generic Group — Multi Phase

Application	No. of Units	Operating Hrs (× 10^6 Hrs)	No. of Failures	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	25	.59965	26	.01139	.3658	8.885	.9996	.9936
Intermediate Wastewater Pumping	14	1.04999	2	.003575	.01788	6.000	1.0000	.9999
Screening/Communition	3	1.216	0	.003601	—	—	1.0000	1.0000
Clarifier Circular Center Drive	62	2.553	20	.009573	.01893	2.600	1.000	.9983
Clarifier Square/ Rectangular Peripheral	28	3.1224	0	.001403	—	—	1.0000	.9999
Return Activated Sludge Handling	27	1.022679	48	.001745	.1562	5.313	.9997	.9993
Recirculation Pumping	14	.3541	6	.007951	.2385	12.50	.9998	.9842
Oxygen Generation/ Storage	5	.05639	0	.07767	—	—	1.000	1.000
Dissolved Air Production	11	.52546	22	.04850	.5214	8.455	.9996	.9912
Dissolved Air/O_2 Production	2	.03613	2	.06061	.2424	1.000	.9999	.9999
Rotating Biological Contactor	56	1.255	56	0.0	.1047	7.857	.9996	.9993
Mechanical Aerators	24	.4510	0	.009713	—	—	1.000	1.000
Secondary Sludge Pumping	14	.25293	1	.01608	.007421	2.000	1.000	1.000
TOTAL	285	12.494729	183	.000682	6.85266	.998	.0069	.9999

TABLE 1.5.3.3. RELIABILITY AND MAINTENANCE DATA FOR MOTORS – VARIABLE SPEED, AC BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Intermediate Wastewater Pumping	1	1	.01807	.0181	–	–	.00465	0.0	7.273	8.00	.9993	.9992
Return Activated Sludge Handling	16	1	.28907	.1729	.01081	.4033	.07432	.01420	.02841	8.00	1.00	.9999
TOTAL	17	2	.30714	.11482	.01081	.1729	.05795	.01257	8.00	.999	.0503	.9998

TABLE 1.5.3.4. RELIABILITY AND MAINTENANCE DATA FOR MOTORS – DC EXCITER BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	4	4	.05431	.01163	–	–	.006795	2.702	1.452	5.00	.9996	.9889
Intermediate Wastewater Pumping	1	2	.01807	.006764	–	–	.003395	0.0	14.55	1.00	.9999	.9947
TOTAL	5	6	.07238	.010884	.006764	.01163	.006861	1.622	1.598	3.66	.9903	.9903

TABLE 1.5.3.5. RELIABILITY AND MAINTENANCE DATA FOR MOTORS – GAS ENGINES BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	2	1	.03978	.02380	–	–	.01023	10.57	10.57	24.00	.9990	.9342

TABLE 1.5.4.1. RELIABILITY AND MAINTENANCE DATA FOR COMPRESSORS – SINGLE STAGE CENTRIFUGAL BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Dissolved Air Production	3	1	.03632	.02173	–	–	.009337	1.487	1.206	8.00	.9996	.9850
Dissolved Air/O_2 Application	5	4	.09034	.01934	–	–	.01130	.01939	.4267	2.75	.9999	.9996
TOTAL	8	5	.12666	.02242	.01934	.02173	.01369	.16854	.3199	3.80	.9999	.9955

TABLE 1.5.4.2. RELIABILITY AND MAINTENANCE DATA FOR COMPRESSORS – MULTI STAGE CENTRIFUGAL BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Dissolved Air Production	11	96	.52547	.005438	.005030	.01487	.004785	.0727	.5046689	.8125375	.99987	.99150
Dissolved Air/O_2 Production	1	0	.01807	.02689	–	–	.007847	.2424	0.0	–	1.0	1.0
TOTAL	12	96	.54354	.005618	.005438	.02689	.004952	.0651	.4723294	.8125375	.99987	.99179

TABLE 1.5.4.3. RELIABILITY AND MAINTENANCE DATA FOR COMPRESSORS – MULTI STAGE – HIGH PRESSURE BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Oxygen Generation/ Storage	5	0	.05639	.08392	.02933	.05459	.02449	.0776659	0.0	–	1.0	1.0

TABLE 1.5.5.1. RELIABILITY AND MAINTAINABILITY DATA ON DIFFUSERS, AIR/WATER—RBC SHAFT BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Rotating Biological Contactor	55	0	1.232	1.834	—	—	.5352	.003555	—	—	1.0	1.0

TABLE 1.5.5.2. RELIABILITY AND MAINTAINABILITY DATA ON DIFFUSERS, AIR/WATER—WASTE TO MEDIA BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Trickling Filter— Rotary Distributor	40	223	1.2824	.01263	—	—	.01263	.000078	.1591	8.305	.9993	.9982

TABLE 1.5.6.1. RELIABILITY AND MAINTAINABILITY DATA ON VALVES—GATE BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	5	9	.06789	.007023	.006266	.008123	.004779	0.0	2.245	2.667	.9996	.9356
Intermediate Wastewater Pumping	2	2	.03613	.01353	.01081	.01081	.006789	0.0	3.636	8.0	.9994	.9969
TOTAL	7	11	.10402	.008929	.007023	.01353	.006266	0.0	1.4074	3.6363	.99947	.95693

TABLE 1.5.6.2. RELIABILITY AND MAINTAINABILITY DATA ON VALVES – BALL BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	1	1	.01916	.01146	–	–	.004927	0.0	43.89	110.0	.9905	.8685

TABLE 1.5.6.3. RELIABILITY AND MAINTAINABILITY DATA ON VALVES – BUTTERFLY BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Oxygen Generation/ Storage	3	0	.03668	.05459	–	–	.01593	.1194	–	–	1.0	1.0
Dissolved Air/O_2 Production	1	1	.01807	.01081	–	–	.004645	0.0	1.455	1.0	.9999	.9998
TOTAL	4	1	.05475	–	–	–	–	.05999	.12005	1.0	.999967	.999934

TABLE 1.5.6.4. RELIABILITY AND MAINTAINABILITY DATA ON VALVES – GATE BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	1	0	.01916	.02852	–	–	.008322	.2286	–	–	1.0	1.0

TABLE 1.5.7.1. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS

Mean Time Between Failures (MTBF) By Application
Broad Classification — Controls
Generic Group — Electical

Application	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)
Raw Wastewater Pumping	21	14	.5487	.03742	.03268	.03888	.02726
Intermediate Wastewater Pumping	15	5	1.0812	.1907	.01161	.6144	.1166
Screening/Communition	3	0	1.216	1.810	—	—	.5283
Clarifier Circular Center Drive	53	21	2.47907	.1144	.01081	.1191	.08796
Clarifier Square/ Rectangular Peripheral	27	0	3.0971	4.609	.5270	2.512	1.345
Return Activated Sludge Handling	28	56	1.0547	.018585	.000432	.01895	.015785
Recirculation Pumping	14	7	.3541	.04618	—	—	.03008
Oxygen Generation/ Storage	5	0	.05639	.08392	—	—	.02449
Dissolved Air Production	6	9	.4709	.04871	—	—	.03315
Rotating Biological Contactor	56	0	1.255	1.807	—	—	.5449
Mechanical Aerators	26	8	.4871	.05620	.01081	.06116	.03748
Secondary Sludge Pumping	15	2	.2537	.09497	—	—	.04766
TOTAL	269	122	12.35396	.100643	.018585	4.609	.089939

TABLE 1.5.7.2. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS

Maintenance Statistics By Application
Broad Classification — Controls
Generic Group — Electrical

Application	No. of Units	Operating Hrs ($\times 10^6$ Hrs)	No. of Failures	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	21	.5487	14	.004562	.157737	4.643	.999854	.999509
Intermediate Wastewater Pumping	15	1.0812	5	.010805	.084259	6.0	.999975	.997439
Screening/Communition	3	1.216	0	.003601	0.0	—	1.0	1.0
Clarifier Circular Center Drive	53	2.47907	21	.001300	.005802	2.00	.999999	.999999
Clarifier Square/ Rectangular Peripheral	27	3.0971	0	.001466	0.0	—	1.0	.999891
Return Activated Sludge Handling	28	1.05472	56	.000741	.058123	2.60705	.999888	.999809
Recirculation Pumping	14	.3541	7	.007951	.07951	5.571	.9999	.9845
Oxygen Generation/ Storage	5	.05639	0	.07767	0.0	—	1.0	1.0
Dissolved Air Production	6	.4709	9	.00155	.1457	1.333	1.0	.9999
Rotating Biological Contactor	56	1.255	0	.003491	0.0	—	1.0	1.0
Mechanical Aerators	26	.48707	8	.000692	.039774	1.749963	.999974	.999985
Secondary Sludge Pumping	15	.2537	2	.01496	.01381	2.5	1.0	.9982
TOTAL	269	12.35395	122	.000281	.002114	2.893366	.999979	.999225

TABLE 1.5.7.3. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS—MECHANICAL BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	1	0	.02240	.03334	—	—	.00973	.1955	0.0	—	1.0	1.0
Intermediate Wastewater Pumping	3	2	.04553	.01705	—	—	.008554	.06413	1.924	8.0	.9995	.9976
TOTAL	4	2	.06793	.03123	.01705	.03334	.012817	.04835	.967169	8.0	.9997	.99839

TABLE 1.5.7.4. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS—PRESSURE (FLUID) BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Secondary Sludge Pumping	6	1	.1084	.06485	—	—	.02787	.04714	.0404	3.0	1.0	.9999
Chlorine, Gaseous	6	16	.5232	.03140	—	—	.02331	0.0	.3014	8.563	.9997	.9858
TOTAL	12	17	.6316	.03578	.03140	.06485	.02676	.00405	.128303	8.23576	.99975	.988219

TABLE 1.5.7.5. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS—PRESSURE-AIR BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Chlorine, Gaseous	10	9	.1807	.01869	—	—	.01272	.009697	.1309	3.556	.9998	.9998

TABLE 1.5.7.6. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS—CHLORINATORS BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Chlorine, Gaseous	3	8	.03408	.003932	—	—	.002623	0.0	17.82	5.375	.9986	.9982

TABLE 1.5.8.1. RELIABILITY AND MAINTENANCE DATA FOR CONVEYORS—CHAIN (BAR SCREEN) BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Screening/Communition	3	19	1.214	.06175	—	—	.04688	0.0	.1371	.9474	1.0	.9999

TABLE 1.5.8.2. RELIABILITY AND MAINTENANCE DATA FOR CONVEYORS—SLUDGE COLLECTOR BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Square/ Rectangular Peripheral	13	7	2.743	.3577	.2202	1.570	.2331	.0009825	.1651	15.14	1.0	.9998

TABLE 1.6.1.1. RELIABILITY AND MAINTENANCE DATA ON PUMPS—OPEN IMPELLER CENTRIFUGAL BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-10,000	33	28	1.1357	.03964	.03569	.1678	.03146	.001987	.075762	6.786	.99982	.99980
10,001-20,000	11	22	.3866	.01706	—	—	01319	.00103	.652	4.136	.9998	.9979
20,001-100,000	9	3	.3604	.09819	—	—	.05395	.009452	.7778	73.0	.9993	.9857
Over 100,000	17	44	.23472	.00526	.005068	.005607	.00436	.099822	1.480809	5.887	.99888	.93208
TOTAL	70	97	2.11742	.021662	.005068	.1678	.019105	.003428	.094773	7.825	.99962	.98955

TABLE 1.6.1.2. RELIABILITY AND MAINTENANCE DATA ON PUMPS—PROPELLER, AXIAL FLOW BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
10,001-20,000	22	3	.41189	.1123	.01378	.5377	.061476	.01212	—	—	1.0	.99987
20,001-100,000	17	15	1.1621	.074256	.02602	.1838	.054559	.001108	.227927	17.467	.99975	.99035
Over 100,000	10	5	.18063	.03197	.006374	.2151	.019528	.237616	1.934614	4.0	.99988	.99816
TOTAL	49	23	1.75462	.074197	.006374	.5377	.057623	.006265	.114107	16.783	.99975	.99311

TABLE 1.6.2.1. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS — CONCENTRIC REDUCER BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0—1	4	2	.07516	.02814	—	—	.01412	.02914	.1748	2.0	.9999	.9999
101-500	14	0	.2529	.3764	—	—	.04896	.01732	0.0		1.0	1.0
TOTAL	18	2	.32806	.12264	.02814	.3764	.061898	.01187	.00890	2.0	.99998	.99998

TABLE 1.6.2.2. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS — PARALLEL SHAFT BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
6-25	56	0	1.255	1.867	—	—	.5449	.003491	0.0	—	1.0	1.0
101-500	6	0	.1127	.1678	—	—	.04896	.03885	0.0	—	1.0	1.0
Over 500	11	2	.53399	.01996	.09384	.1763	.11075	.00671	.2863	32.0	.9998	.9996
TOTAL	73	2	1.90169	.7109	.01996	1.867	.3588	.002241	.012075	32.0	.99995	.99990

TABLE 1.6.2.3. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS — RIGHT ANGLE SHAFT BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	49	180	3.481	.03857	.009929	2.512	.03385	.001027	.01310	1.4	.99995	.99989
101-500	2	0	.03978	.05919	—	—	.01728	.1101	0.0	—	1.0	1.0
TOTAL	51	180	3.52078	.019479	.03857	.05919	.017747	.001025	.01244	1.4	.99995	.99989

TABLE 1.6.2.4. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS — VERTICAL SHAFT BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	9	32	.6287	.01925	—	—	.01551	.002322	.1455	.9688	1.00	.9931
26-100	35	10	.6497	.06091	—	—	.04217	.002119	.06645	5.2	.9999	.9999
101-500	7	2	.1265	.04735	—	—	.02376	.02968	.05937	3.0	.9999	.9999
TOTAL	51	44	1.4049	.03146	.01925	.06091	.02611	.001223	.03331	2.023	.99994	.99686

TABLE 1.6.2.5. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS — VARIABLE SPEED DRIVE, HYDRAULIC BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	13	0	.2349	.3495	—	—	.1020	.01865	0.0	—	1.0	1.0

TABLE 1.6.2.6. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS — VARIABLE SPEED DRIVE, OTHER BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	3	8	.06796	.007841	—	—	.00523	.02148	1.031	2.5	.9997	.9996
Over 500	1	0	.01807	.02689	—	—	.007847	7.273	0.0	—	1.0	.9992
TOTAL	4	8	.08603	.018422	.007841	.02689	.010754	.3946	.6108	2.5	.99976	.99952

TABLE 1.6.2.7. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS – GEAR BOX BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	11	24	1.483	.06016	.03924	.1725	.04693	0.0	.1659	6.04	.99988	.99974
1-5	15	38	.3794	.009816	–	–	.008041	.004618	.3756	1.342	.9999	.9984
6-25	5	1	1.055	.6313	–	–	.2713	.003321	.1594	25.0	1.0	.9996
26-100	1	2	.09286	.03476	–	–	.01745	0.0	.5660	4.0	.9999	.9998
TOTAL	32	65	3.01026	.045783	.009816	.6313	.039323	.000455	.059560	3.523	.99993	.99952

TABLE 1.6.2.8. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS – CHAIN DRIVE BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
1-5	4	5	.1012	.01785	–	–	.01091	0.0	1.364	8.0	.9996	.9945

TABLE 1.6.2.9. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS – BELT DRIVE BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	3	5	.5160	.09101			.05564	0.0	.08488	1.8	1.0	.9916

TABLE 1.6.3.1. RELIABILITY AND MAINTENANCE DATA ON MOTORS — MULTIPHASE BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	70	20	4.241	.2147	.1236	2.512	.1349	.00522	.01009	2.6	1.0	.99890
1-5	15	0	.3794	.5646	—	—	.1648	.01152	0.0	—	1.0	1.0
6-25	64	56	3.526	.0621	.0222	1.81	.0527	.00015	.03261	7.857	.99986	.99975
26-100	60	59	2.702	.0460	.0210	1.334	.0347	.00108	.03098	4.96651	.99988	.99962
101-500	52	18	.9590	.0540	.0135	.3226	.0332	.00328	.10599	12.05617	.99977	.99332
Over 500	24	30	.6870	.0231	.00983	.09831	.0157	.02683	.24917	8.433	.99960	.98914
TOTAL	285	183	12.4947	.0680	.0231	.5646	.0620	.00068	.00695	6.85801	.99989	.99836

TABLE 1.6.3.2. RELIABILITY AND MAINTENANCE DATA ON MOTORS — VARIABLE SPEED, AC BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	15	0	.2710	.4033	—	—	.1177	.01616	—	—	1.0	1.0
Over 500	2	2	.03614	.01351	.01081	.01081	.00682	0.0	3.6365	8.0	.9993	.9992
TOTAL	17	2	.30714	.11482	.01351	.4033	.05795	.01258	.050340	8.0	.99992	.99991

TABLE 1.6.3.3. RELIABILITY AND MAINTENANCE DATA ON MOTORS — DC EXCITER BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Over 500	5	6	.07238	.010884	.006764	.01163	.006861	1.6219466	1.5980961	3.666667	.9996749	.990348

TABLE 1.6.3.4. RELIABILITY AND MAINTENANCE DATA ON MOTORS — GAS ENGINE BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	2	1	.03978	.02380	–	–	.01023	10.57	10.57	24.00	.9990	.9342

TABLE 1.6.4.1. RELIABILITY AND MAINTENANCE DATA ON COMPRESSORS — SINGLE STAGE CENTRIFUGAL BY SIZE

Size (Cubic Feet Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
001-10,000	5	4	.09034	.01934	–	–	.01130	.01939	.4267	2.75	.9999	.9996
Over 20,000	3	1	.03632	.02173	–	–	.009337	1.487	1.206	8.0	.9996	.9850
TOTAL	8	5	.12666	.02242	.01934	.02173	.01369	.16854	.319898	3.80	.9998	.9954

TABLE 1.6.4.2. RELIABILITY AND MAINTENANCE DATA ON COMPRESSORS — MULTI STAGE CENTRIFUGAL BY SIZE

Size (Cubic Feet Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
1,001-10,000	1	0	.01809	.02689	–	–	.007847	.2424	0.0	–	1.0	1.0
10,001-20,000	5	3	.05457	.01487	–	–	.008168	.03211	1.445	6.0	.9996	.9993
Over 20,000	6	9	.47090	.005030	–	–	.004417	.1457	.8929	0.6452	.9999	.9999
TOTAL	12	96	.54354	.005618	.005030	.02689	.004952	.06513	.44723	.81254	.99987	.99179

TABLE 1.6.4.3. RELIABILITY AND MAINTENANCE DATA ON COMPRESSORS – MULTI STAGE HIGH PRESSURE BY SIZE

Size (Cubic Feet Per Minute)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-1,000	3	0	.03668	.05459	–	–	.01593	.1194	0.0	–	1.0	1.0
1,001-10,000	2	0	.01971	.02933	–	–	.008560	.2222	0.0	–	1.0	1.0
TOTAL	5	0	.05639	.08392	.01971	.03668	.02449	.07767	0.0	–	1.0	1.0

TABLE 1.6.5.1. RELIABILITY AND MAINTENANCE DATA ON DIFFUSERS, AIR/WATER – RBC SHAFT BY SIZE

Size	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
6-25 Horsepower	55	0	1.232	1.834	–	–	.5852	.01263	–	–	.01160	–

TABLE 1.6.5.2. RELIABILITY AND MAINTENANCE DATA ON DIFFUSERS, AIR/WATER – WASTE TO MEDIA BY SIZE

Size (Gallons per Minute)	No. of Units	Operating Hrs ($\times 10^6$)	No. of Failures	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
10,001-20,000	40	2.824	223	.000078	.1591	8.305	.9993	.9982

TABLE 1.6.6.1. RELIABILITY AND MAINTENANCE DATA ON VALVES — GATE BY SIZE

Size (Inches)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
25-48	2	2	.03165	.01183	.01081	.01146	.005972	0.0	4.15224	8.00	.999169	.999064
Over 48	5	9	.07238	.007501	.006266	.01081	.005097	0.0	2.10575	2.6667	.99960	.938500
TOTAL	7	11	.10403	.008929	.007023	.01353	.006266	0.0	1.40743	3.6364	.99947	.95693

TABLE 1.6.6.2. RELIABILITY AND MAINTENANCE DATA ON VALVES — BALL BY SIZE

Size (Inches)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
25-48	1	1	.01916	.01146	—	—	.004927	0.0	43.89	110.0	.9905	.8685

TABLE 1.6.6.3. RELIABILITY AND MAINTENANCE DATA ON VALVES — BUTTERFLY BY SIZE

Size (Inches)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-6	3	0	.03668	.05459	—	—	.01593	.1194	—	—	1.0	1.0
13-24	1	1	.01807	.01081	—	—	.004645	0.0	1.455	1.00	.9999	.9998
TOTAL	4	1	.05475	.032589	.01081	.05459	.014075	.05999	.12005	1.00	.999967	.999934

TABLE 1.6.6.4. RELIABILITY AND MAINTENANCE DATA ON VALVES—PLUG BY SIZE

Size (Inches)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
25-48	1	1	.01916	.02852	—	—	.008322	.2286	—	—	1.0	1.0

TABLE 1.6.7.1. RELIABILITY AND MAINTENANCE DATA ON CONTROLS—ELECTRICAL BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	60	20	4.149	.20092	.1191	2.512	.15686	.00083	.00296	2.05	1.0	.99992
1-5	14	0	.3541	.50950	—	—	.15362	.01325	0.0	—	1.0	1.0
6-25	64	0	3.526	4.6849	1.570	1.867	1.41258	.00124	0.0	—	1.0	1.0
26-100	56	69	1.8211	.026109	.01895	.06116	.022521	.00035	.02615	2.37672	.99988	.99993
101-500	60	19	1.92154	.09779	.01081	.6144	.07419	.00274	.02215	5.57895	.99672	.99995
Over 500	15	14	.58221	.03974	.004324	.08392	.02889	.00301	.12236	2.99979	.99535	.99993
TOTAL	269	122	12.35395	.100843	.026109	4.6849	.089939	.00028	.00211	2.89337	.99998	.99922

TABLE 1.6.7.2. RELIABILITY AND MAINTENANCE DATA ON CONTROLS—MECHANICAL BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	1	0	.0224	.03334	—	—	.00973	.1955	0.0	—	1.0	1.0
Over 500	3	2	.04563	.01705	—	—	.008554	.08413	1.924	8.0	.9995	.9976
TOTAL	4	2	.06793	.03123	.01705	.03334	.012817	.04835	.96717	8.0	.99966	.99839

TABLE 1.6.7.3. RELIABILITY AND MAINTENANCE DATA ON CONTROLS—PRESSURE (FLUID) BY SIZE

Size	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500 (HP)	6	1	.1084	.06485	—	—	.02787	.04714	.0404	3.0	1.0	.9999
Over 2000 Lbs. Chemical	6	16	.5236	.03140	—	—	.02331	0.0	.3014	8.563	.9997	.9858
TOTAL	12	17	.6316	.03578	.03140	.06485	.02676	.00405	.12830	8.23576	.99975	.98822

TABLE 1.6.7.4. RELIABILITY AND MAINTENANCE DATA ON CONTROLS—PRESSURE—AIR BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Over 2000 Lbs. Chemical	10	.1809	9	.01869	—	—	.01272	.009697	.1309	3.556	.9998	.9998

TABLE 1.6.8.1. RELIABILITY AND MAINTENANCE DATA ON CONVEYORS – CHAIN (BAR SCREEN) BY SIZE

Size	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Over 48 Inches	3	19	1.214	.06175	–	–	.04688	0.0	.1371	.9474	1.0	.9999

TABLE 1.6.8.2. RELIABILITY AND MAINTENANCE DATA ON CONVEYORS – SLUDGE COLLECTOR BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	8	7	16.88	.2202	–	–	.1434	.009729	.4359	15.14	.9999	.9996
6-25	5	0	1.055	1.570	–	–	.4583	.004151	–	–	1.000	1.000
TOTAL	13	7	2.743	.35856	.2202	1.570	.23345	.000982	.165075	15.14	.99993	.99975

TABLE 2.1.1. PUMPS — DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Impeller Wear Ring, or Plate	17	.177
2	Solenoid Valve	16	.167
3	Bearing, Ball, Single Row	14	.146
4	Bearing, Ball, Double Row	8	.083
5	Controller	8	.083
6	Bearing, Cast, Pillow	5	.052
7	Complete Bearing Replacement	5	.052
8	Seal, Packed, not Lubricated	3	.031
9	Coupling	3	.031
10	Bearing, Thrust	3	.031
11	Pump Impeller	2	.021
12	Drive Belt	2	.021
13	Case, Pump	2	.021

TABLE 2.1.2. POWER TRANSMISSIONS — DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Drive Belt	133	.453
2	Bearing, Ball, Double Row	48	.163
3	Shear Pin	39	.133
4	Seal, other	24	.082
5	Bearing, Ball, Single Row	11	.037
6	Shaft, Drive	9	.031
7	Controller	8	.027
8	Coupling	5	.017
9	Chain, Pintle	5	.017
10	Pulley, Belt Drive	4	.013
11	Skimmer	2	.007

TABLE 2.1.3. MOTORS – DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	58	.347
2	Brushes	38	.228
3	Coupling	19	.114
4	Motor Windings	16	.096
5	Bearing, Ball, Double Row	11	.066
6	Controller	4	.024
7	Shaft Sleeve	3	.018
8	Relay	3	.018
9	Motor Armature	3	.018
10	Seal, Packed, not Lubricated	2	.012
11	Bearing, Ball, Single Row	2	.012
12	Bearing, Thrust	2	.012
13	Overload Relay	2	.012
14	Case, Motor	2	.012

TABLE 2.1.4. COMPRESSORS – DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Component Type	No Of Failures	Relative Frequency
1	Coupling	3	.231
2	Bearing, Ball, Single Row	3	.231
3	Switch, Electric	3	.231
4	Pump Impeller	2	.154
5	Brushes	1	.077
6	Pipe Broken	1	.077

TABLE 2.1.5. DIFFUSERS, AIR/WATER—DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent	No. of Failures	Relative Frequency
1	Tie Rod	107	.480
2	Seal, Single, Mechanical	49	.220
3	Bearing, Thrust	36	.161
4	Bearing, Ball, Single Row	25	.112
5	End Gate	5	.022
6	Experimental/Prototype Bearing	1	.005

TABLE 2.1.6. VALVES—DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Component Type	No. Of Failures	Relative Frequency
1	Seal, Packed Water, Oil, Grease Lubricated	7	.538
2	Control Valve	3	.231
3	Seal, other	1	.077
4	Controller	1	.077
5	Solenoid valve	1	.077

TABLE 2.1.7. CONTROLS—DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	46	.371
2	Magnetic Starter	26	.210
3	Overload Relay	13	.105
4	Relay	11	.089
5	Switch, Electric	11	.089
6	Seal, Single, Mechanical	3	.024
7	Seal, other	3	.024
8	Complete Bearing Replacement	3	.024
9	Electrical Timer	2	.016
10	Control Valve	2	.016

TABLE 2.1.8. CONVEYOR—DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Rake Guides	19	.731
2	Collector mechanism	5	.192
3	Plastic chain and Flights	1	.038
4	Pipe Broken	1	.038

TABLE 2.2.1.1. PUMPS—OPEN IMPELLER CENTRIFUGAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Impeller Wear Ring or Plate	15	.197
2	Seal, Packed, Water, Oil, Grease Lubricated	14	.184
3	Solenoid Valve	14	.184
4	Bearing, Ball, Double Row	6	.079
5	Bearing, Cast, Pillow	5	.066

TABLE 2.2.1.2. PUMPS—PROPELLER, AXIAL FLOW

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	4	.200
2	Complete Bearing Replacement	4	.200
3	Impeller Wear Ring or Plate	2	.100
4	Bearing, Ball, Double Row	2	.100
5	Bearing, Thrust	2	.100
6	Solenoid Valve	2	.100

TABLE 2.2.2.1. POWER TRANSMISSION—RIGHT ANGLE SHAFT

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Drive Belt	127	.706
2	Bearing, Ball, Double Row	45	.250
3	Pulley, Belt Drive	3	.017
4	Coupling	2	.011

TABLE 2.2.2.2. POWER TRANSMISSION—VERTICAL SHAFT

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, other	20	.445
2	Bearing, Ball, Single Row	11	.245
3	Shaft, Drive	8	.178

TABLE 2.2.2.3. POWER TRANSMISSION—VARIABLE SPEED DRIVE, OTHER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	8	.889
2	Brushes	1	.111

TABLE 2.2.2.4. POWER TRANSMISSION—GEAR BOX

Rank	Sbucomponent Type	No. Of Failures	Relative Frequency
1	Shear Pin	38	.826
2	Seal, other	4	.087
3	Coupling	3	.065
4	Complete Bearing Replacement	1	.022

TABLE 2.2.3.1. MOTORS—MULTI-PHASE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	57	.385
2	Brushes	24	.162
3	Coupling	19	.128
4	Motor Windings	16	.108
5	Bearing, Ball, Double Row	10	.068

TABLE 2.2.3.2. MOTORS—VARIABLE SPEED AC

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	1	.500
2	Controller	1	.500

TABLE 2.2.3.3. MOTORS – DC EXCITER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	14	.933
2	Motor Armature	1	.067

TABLE 2.2.3.4. MOTORS – GASOLINE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	1	.500
2	Replaced Piston	1	.500

TABLE 2.2.4.1. COMPRESSORS – SINGLE STAGE CENTRIFUGAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Single Row	3	.429
2	Switch, Electric	2	.286
3	Coupling	1	.143
4	Brushes	1	.143

TABLE 2.2.4.2. COMPRESSORS—MULTI STAGE CENTRIFUGAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Pump Impeller	2	.333
2	Coupling	2	.333
3	Case, Motor	1	.167
4	Pipe Broken	1	.167

TABLE 2.2.5.1. DIFFUSERS, AIR/WATER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Tie Rod	107	.480
2	Seal, Single, Mechanical	49	.220
3	Bearing, Thrust	36	.161
4	Bearing, Ball, Single Row	25	.112
5	End Gate	5	.022
6	Experimental/Prototype Bearing	1	.005

TABLE 2.2.6.1. VALVES—GATE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, Packed, Water, Oil, Grease Lubricated	7	.636
2	Seal, other	1	.091
3	Controller	1	.091
4	Solenoid Valve	1	.091
5	Control Valve	1	.091

TABLE 2.2.7.1. CONTROLS—ELECTRICAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	32	.348
2	Magnetic Starter	23	.250
3	Overload Relay	13	.141
4	Switch, Electric	10	.109
5	Relay	9	.098

TABLE 2.2.7.2. CONTROLS—MECHANICAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Switch, Electric	1	.500
2	Motor Windings	1	.500

TABLE 2.2.7.3. CONTROLS—PRESSURE, FLUID

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	5	.385
2	Magnetic Starter	3	.231
3	Complete Bearing Replacement	3	.231

TABLE 2.2.7.4. CONTROLS—CHLORINATORS

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, other	3	.375
2	Relay	2	.250
3	Control Valve	2	.250
4	Gear, Rack	1	.125

TABLE 2.2.8.1. CONVEYOR—SLUDGE COLLECTOR

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Collector Mechanism	5	.714
2	Plastic Chain and Flights	1	.143
3	Pipe Broken	1	.143

TABLE 2.3.1.1. PUMPS—RAW WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Impeller Wear Ring, or Plate	15	.246
2	Seal, Packed, Water, Oil, Grease Lubricated	14	.230
3	Solenoid Valve	14	.230
4	Bearing, Cast, Pillow	5	.082
5	Seal, Packed, not Lubricated	3	.049

TABLE 2.3.1.2. PUMPS—INTERMEDIATE WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	8	.572
2	Seal, other	1	.071
3	Coupling	1	.071
4	Drive Belt	1	.071
5	Relay	1	.071
6	Switch, Electric	1	.071
7	Brushes	1	.071

TABLE 2.3.1.3. PUMPS—RETURN ACTIVATED SLUDGE HANDLING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	5	.714
2	Coupling	2	.286

TABLE 2.3.1.4. PUMPS—RECIRCULATION PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	4	.286
2	Impeller Wear Ring, or Plate	2	.143
3	Bearing, Ball, Double Row	2	.143
4	Bearing, Thrust	2	.143
5	Solenoid Valve	2	.143

TABLE 2.3.2.1. POWER TRANSMISSION — CLARIFIER CENTER CIRCULAR DRIVE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Drive Belt	133	.596
2	Bearing, Ball, Double Row	45	.202
3	Seal, other	20	.090
4	Shaft, Drive	9	.040
5	Bearing, Ball, Single Row	5	.022
6	Pulley, Drive Belt	4	.018

TABLE 2.3.2.2. POWER TRANSMISSION — CLARIFIER SQUARE/RECTANGULAR, PERIPHERAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Shear Pin	38	.809
2	Chain, Pintle	5	.106
3	Coupling	3	.064
4	Complete Bearing Replacement	1	.021

TABLE 2.3.2.3. POWER TRANSMISSION — MECHANICAL AERATORS

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Single Row	6	.461
2	Seal, other	4	.308
3	Seal, Single Mechanical	1	.077
4	Seal, Packed, Water, Oil, Grease Lubricated	1	.077
5	Bearing Ball, Double Row	1	.077

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TABLE 2.3.3.1. MOTORS—RAW WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	16	.381
2	Motor Windings	13	.310
3	Relay	3	.071
4	Motor Armature	3	.071
5	Controller	2	.048

TABLE 2.3.3.2. MOTORS—INTERMEDIATE WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	2	.667
2	Controller	1	.133

TABLE 2.3.3.3. MOTORS—CLARIFIER CIRCULAR CENTER DRIVE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Coupling	19	.826
2	Bearing, Ball, Single Throw	2	.087
3	Bearing, Ball, Double Throw	2	.087

TABLE 2.3.3.4. MOTORS—RETURN ACTIVATED SLUDGE HANDLING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	9	.500
2	Bearing, Ball, Double Row	5	.278
3	Seal, Packed, not Lubricated	2	.111

TABLE 2.3.3.5. MOTORS—RECIRCULATION PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Shaft, Sleeve	2	.333
2	Bearing, Ball, Double Row	2	.333
3	Bearing, Thrust	1	.167
4	Complete Bearing Replacement	1	.167

TABLE 2.3.3.6. MOTORS—DISSOLVED AIR PRODUCTION

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	11	.688
2	Motor Windings	2	.125
3	Case, Motor	2	.125
4	Bearing, Ball, Double Row	1	.062

TABLE 2.3.4.1. COMPRESSORS—DISSOLVED AIR PRODUCTION

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Coupling	3	.333
2	Pump Impeller	2	.222
3	Switch, Electric	1	.111
4	Case, Motor	1	.111
5	Brushes	1	.111
6	Pipe Broken	1	.111

TABLE 2.3.4.2. COMPRESSORS—DISSOLVED AIR/O_2 APPLICATION

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	3	.750
2	Switch, Electric	1	.250

TABLE 2.3.5.1. DIFFUSERS, AIR/WATER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Tie Rod	107	.480
2	Seal, Single, Mechanical	49	.220
3	Bearing, Thrust	36	.161
4	Bearing, Ball, Single Row	25	.112
5	End Gate	5	.022
6	Experimental/Prototype Bearing	1	.005

TABLE 2.3.6.1. VALVES—RAW WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, Packed, Water Oil, Grease Lubricated	7	.700
2	Seal, other	1	.100
3	Controller	1	.100
4	Control Valve	1	.100

TABLE 2.3.6.2. VALVES—INTERMEDIATE WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Solenoid Valve	1	.500
2	Control Valve	1	.500

TABLE 2.3.7.1. CONTROLS—RAW WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Magnetic Starter	11	.846
2	Switch, Electric	1	.077
3	Solenoid Valve	1	.077

TABLE 2.3.7.2. CONTROLS—INTERMEDIATE WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Relay	2	.222
2	Overload Relay	2	.222
3	Switch, Electric	2	.222
4	Controller	2	.222
5	Motor Windings	1	.111

TABLE 2.3.7.3. CONTROLS—CLARIFIER CENTER CIRCULAR DRIVE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Magnetic Starter	8	.421
2	Overload Relay	5	.263
3	Switch, Electric	4	.211
4	Relay	1	.053
5	Controller	1	.053

TABLE 2.3.7.4. CONTROLS—RETURN ACTIVATED SLUDGE HANDLING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	22	.786
2	Magnetic Starter	4	.143
3	Electrical Timer	2	.071

TABLE 2.3.7.5. CONTROLS—RECIRCULATION PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Overload Relay	3	.429
2	Seal, Single, Mechanical	2	.286
3	Switch, Electric	1	.143
4	Controller	1	.143

TABLE 2.3.7.6. CONTROLS—DISSOLVED AIR PRODUCTION

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	4	.445
2	Switch, Electric	3	.333
3	Relay	2	.222

TABLE 2.3.7.7. CONTROLS—MECHANICAL AERATORS

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Relay	4	.500
2	Overload Relay	3	.375
3	Switch, Electric	1	.125

TABLE 2.3.7.8. CONTROLS—CHLORINE, GASEOUS

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	13	.448
2	Seal, other	3	.103
3	Magnetic Starter	3	.103
4	Complete Bearing Replacement	3	.103
5	Relay	2	.069
6	Control Valve	2	.069
7	Seal, Single, Mechanical	1	.035
8	Gear, Rack	1	.035
9	Gear, Pinion	1	.035

TABLE 2.3.8.1. CONVEYOR—CLARIFIER SQUARE/RECTANGULAR PERIPHERAL DRIVE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Collector Mechanism	5	.714
2	Plastic Chain and Flights	1	.143
3	Pipe Broken	1	.143

TABLE 2.4.1.1. PUMPS—0 TO 10,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	5	.714
2	Coupling	2	.286

TABLE 2.4.1.2. PUMPS – 10,001 TO 20,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Impeller Wear Ring, or Plate	15	.600
2	Seal, Packed, not Lubricated	2	.080
3	Bearing, Thrust	2	.080

TABLE 2.4.1.3. PUMPS – 20,001 TO 100,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	4	.308
2	Impeller Wear Ring, or Plate	2	.154
3	Bearing, Ball, Double Row	2	.154
4	Solenoid Valve	2	.154

TABLE 2.4.1.4. PUMPS – OVER 100,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, Packed, Water, Oil, Grease Lubricated	14	.269
2	Solenoid Valve	13	.250
3	Controller	8	.154
4	Bearing, Cast, Pillow	5	.096
5	Drive Belt	2	.038

TABLE 2.4.2.1. POWER TRANSMISSION—0 TO 1 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Drive Belt	133	.588
2	Bearing, Ball, Double Row	45	.199
3	Seal, other	20	.088
4	Shaft, Drive	9	.040
5	Coupling	5	.022
6	Bearing, Ball, Single Row	5	.022
7	Pulley, Belt Drive	4	.018

TABLE 2.4.2.2. POWER TRANSMISSION—2 TO 5 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Shear Pin	38	.884
2	Chain, Pintle	5	.116

TABLE 2.4.2.3. POWER TRANSMISSION—26 TO 100 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Single Row	6	.600
2	Seal, other	4	.400

TABLE 2.4.2.4. POWER TRANSMISSION — 101 TO 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	8	.727
2	Seal, Single, Mechanical	1	.091
3	Seal, Packed, Water, Oil, Grease Lubricated	1	.091
4	Bearing, Ball, Double Row	1	.091

TABLE 2.4.2.5. POWER TRANSMISSION — OVER 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	2	.667
2	Brushes	1	.333

TABLE 2.4.3.1. MOTORS — 0 TO 1 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Coupling	19	.826
2	Bearing, Ball, Single Row	2	.087
3	Bearing, Ball, Double Row	2	.087

TABLE 2.4.3.2. MOTORS—26 TO 100 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Motor Windings	11	.393
2	Brushes	9	.321
3	Bearing, Ball, Double Row	4	.143
4	Seal, Packed, not Lubricated	2	.071
5	Shaft, Sleeve	1	.036
6	Controller	1	.036

TABLE 2.4.3.3. MOTORS—101 TO 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	4	.222
2	Shaft, Sleeve	2	.111
3	Bearing, Thrust	2	.111
4	Overload Relay	2	.111
5	Motor Windings	2	.111
6	Brushes	2	.111
7	Complete Bearing Replacement	2	.111

TABLE 2.4.3.4. MOTORS—OVER 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	27	.643
2	Relay	3	.071
3	Motor Windings	3	.071
4	Controller	3	.071
5	Motor Armature	2	.048
6	Case, Motor	2	.048

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TABLE 2.4.4.1. COMPRESSORS — 1,001 TO 10,000 CUBIC FEET PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Single Row	3	.750
2	Switch, Electric	1	.250

TABLE 2.4.4.2. COMPRESSORS — 10,001 TO 20,000 CUBIC FEET PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Coupling	2	.667
2	Pipe Broken	1	.333

TABLE 2.4.4.3. COMPRESSORS — OVER 20,000 CUBIC FEET PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Pump Impeller	2	.333
2	Switch, Electric	2	.333
3	Coupling	1	.167
4	Brushes	1	.167

TABLE 2.4.5.1. DIFFUSERS, AIR/WATER – 10,001 TO 20,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Tie Rod	107	.480
2	Seal, Single, Mechanical	49	.220
3	Bearing, Thrust	36	.161
4	Bearing, Ball, Single Row	25	.112
5	End Gate	5	.022
6	Experimental/Prototype Bearing	1	.005

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TABLE 2.4.6.1. VALVES – 25 TO 48 INCHES

Rank	Subcomponent Type	No. of Failures	Relative Frequency
1	Seal	1	.333
2	Solenoid Valve	1	.333
3	Control Valve	1	.333

TABLE 2.4.6.2. VALVES – OVER 48 INCHES

Rank	Subcomponent Type	No. of Failures	Relative Frequency
1	Seal, Packed, Water, Oil, Grease Lubricated	7	.778
2	Controller	1	.111
3	Control Valve	1	.111

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TABLE 2.4.7.1. CONTROLS—0 TO 1 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Magnetic Starter	8	.444
2	Overload Relay	5	.278
3	Switch, Electric	4	.222
4	Relay	1	.056

TABLE 2.4.7.2. CONTROLS—26 TO 100 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	21	.512
2	Magnetic Starter	11	.268
3	Relay	4	.098
4	Overload Relay	2	.049
5	Electrical Timer	2	.049

TABLE 2.4.7.3. CONTROLS—101 TO 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	6	.300
2	Overload Relay	5	.250
3	Magnetic Starter	4	.200
4	Seal, Single, Mechanical	2	.100
5	Switch, Electric	2	.100

TABLE 2.4.7.4. CONTROLS – OVER 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	6	.375
2	Relay	4	.250
3	Switch, Electric	4	.250

TABLE 2.4.7.5. CONTROLS – OVER 2000 POUNDS CHEMICAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	13	.448
2	Seal, other	3	.103
3	Magnetic Starter	3	.103
4	Complete Bearing Replacement	3	.103
5	Relay	2	.069
6	Control Valve	2	.069

TABLE 2.4.8.1. CONVEYOR – 0 TO 1 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Collector Mechanism	5	.714
2	Plastic Chain and Flights	1	.143
3	Pipe Broken	1	.143

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TABLE 3.1.1. WWTP REPORT-RELIABILITY OF SLUDGE PROCESSES

Process	Operating Hours ($\times 10^6$ Hrs)	No. of Failures	MTBF ($\times 10^6$ Hrs)	90% CL ($\times 10^6$ Hrs)	Avail.
Sludge Process External to WW Treat. Process	.780	400	.00195	.00183	.997
Anaerobic Digestion	.678	40	.0167	.0137	1.000
Incineration	.374	454	.000824	.000776	.723
Sludge Thickening DAF	.406	702	.000577	.000583	.994
Vacuum Filter	.697	1150	.000606	.000583	.931

APPENDIX E

WASTEWATER RELIABILITY ANALYSIS PROGRAM
USERS MANUAL

INTRODUCTION

The Wastewater Reliability Analysis Program (WRAP) was developed in order to derive the desired sorts and calculate reliability, maintainability and availability statistics from the data base gathered from wastewater treatment plants.

The contents of this manual describe the structure of the computer program and the algorithms used to calculate the statistics.

DATA BASE

The data base contains reliability performance information on components in wastewater treatment plants and availability information on sludge treatment processes. The data was gathered from nine operating plants.

The data collection procedure is given in the final report. The data coding system is presented in Appendix A.

DATA RECORDS

The format and content of each data field is shown in Table 1. The data fields are numbered 1 through 28 for a data record. Each data record from the Data Collection Sheet (shown in Figure 1) was entered on a standard 80 column card, and read into a disk file. There are 1,452 records in the data base. These records are listed in Appendix E-1. The data base is contained in a disk file named "DATA2" in the computer program.

TABLE 1. FORMAT AND CONTENT OF DATA CARD RECORD

Field No.	Columns	Number of Digits	Field Content	Format	Data(1) Sheet Field Number
1	1-2	2	Plant Number	I2	1(2)
2	3-6	4	Record Number	I4	1(3)
3	8-9	2	Plant Type	I2	2
4	11-12	2	Plant Unit Operations	I2	3
5	14-15	2	Broad Class of Mechanical Components	I2	4
6	17-20	4	Generic Group	I4	5
7	21-22	2	Application	I2	6
8	23-24	2	Size/Capacity	I2	7
9	25-27	3	Subcomponent	I3	8
10	28-29	2	Criticality	I2	9
11	30-31	2	Month Installed	I2	10(2)
12	32-33	2	Year Installed	I2	10(4)
13	34-35	2	Percent of Time Operating	I2	11
14	36-37	2	Failures	I2	12
15	38-39	2	Failure Mode	I2	13
16	40-41	2	Contributing Cause of Failure	I2	13
17	42-43	2	Calendar Downtime of Function	I2	15
18	44-45	2	Man Hours to Repair	I2	16
19	46-47	2	Environmental Factor	I2	17
20	48-49	2	Part Disposition	I2	18
21	50-52	3	Subcomponent Manufacturer	I3	19
22	53-55	3	Component Manufacturer	I3	20
23	57-58	2	Inventory Information	I2	21
24	60-61	2	Type of Maintenance	I2	22
25	63-67	5	Downtime of Unit Operations	I5	23
26	69-70	2	Month of Data Collection Date	I2	24(2)
27	71-72	2	Year of Data Collection Date	I2	24(4)
28	73-76	4	Actual Clock Time to Repair Unit	I4	25

(1) See Figure 1 for details on the Data Sheet.
(2) First two digits of Data Sheet Field.
(3) Last four digits of Data Sheet Field.
(4) Last two digits of Data Sheet Field.

1 PLANT NUMBER AND RECORD NO.	2 TYPE	3 UNIT OPERATION	4 BROAD CLASSIFICATION	5 GENERIC GROUPS	6 APPLICATION	7 SIZE	8 SUB-COMPONENT	9 CRITICALITY	10 DATE INSTALLED	11 % OPERATING TIME *	12 FAILURES	13 FAILURE MODE	14 CAUSE OF FAILURE	15 CALENDAR DOWN TIME OF FUNCTION	16 MAN HOURS TO REPAIRS	17 ENVIROMENTAL FACTOR	18 PART DISPOSITION	19 SUBCOMPONENT MFR.	20 COMPONENT MFR.	21 PART INV. INFO.	22 TYPE OF MAINT.	23 DOWN TIME OF UNIT OP.	24 COLLECTION OR DECOMISSION-ING DATE	25 ACTIVE CLOCK TIME TO REPAIR

Figure 1. Data Collection Sheet.

COMPUTER PROGRAM CAPABILITIES

WRAP can generate three general types of reports from the data base. These types of reports are:

(1) Reliability, maintainability and availability statistics on components in the wastewater treatment processes in the plants by broad classification, generic groups and application. These reports can be generated across plants, or within plants. Tables 2 and 3 are excerpts from these reports.

(2) Failures by subcomponent codes by size range codes for each combination of broad classification, generic group and application, both across all plants and within plants. Excerpts from these reports are contained in Tables 4 and 5.

(3) Reliability and availability statistics on sludge processes across plants and within plants. Examples of these reports are contained in Tables 6 and 7.

The data base on the wastewater treatment processes can be sorted in any desired order on up to any six data fields at a time (out of the 28 listed in Table 1).

REPORT GENERATION CONTROL

There are eight parameters which control the type of output from WRAP. The program symbols for these parameters are:

(1) NPC is the number of report types desired on a single computer run.

(2) NWWS indicates whether wastewater treatment of sludge processing report is desired. NWWS is set to 1 for wastewater treatment process reports and to 2 for sludge process reports.

TABLE 2. EXCERPTS FROM WASTEWATER TREATMENT PLANT REPORT - RELIABILITY STATISTICS BY GENERIC GROUP/APPLICATION AND SIZE RANGE

```
        BROAD CLASSIFICATION                       GENERIC GROUPS                      APPLICATION
        PUMPS(WITHOUT MOTOR)                  OPEN IMPELLER CENTRIFUGAL PUMP         RAW WASTEWATER PUMPING
  SIZE- CAPACITY                NO.       OPER.   NO.   PM-HRS/    CM-HRS/
                               UNITS       HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

10001-20000 GAL. PER MIN.         11  .3866E 06    22  .1030E-02  .6520E 00  .4136E 01  .1706E 05  .1319E 05  .9998E 00  .9979E 00
20001-100000 GAL. PER MIN.         9  .3604E 06     3  .9452E-02  .7778E 00  .7300E 02  .9819E 05  .5395E 05  .9993E 00  .9857E 00
OVER 100000 GAL. PER MIN.         19  .1807E 06    35  .1039E 00  .1870E 01  .5686E 01  .5068E 04  .4119E 04  .9989E 00  .9534E 00
OVERALL STATISTICS                39  .9277E 06    60  .9442E-02  .3178E 00  .8483E 01  .1530E 05  .1303E 05  .9994E 00  .9845E 00


        BROAD CLASSIFICATION                       GENERIC GROUPS                      APPLICATION
        PUMPS(WITHOUT MOTOR)                  OPEN IMPELLER CENTRIFUGAL PUMP       INTERMEDIATE WASTEWATER PUMPING
  SIZE- CAPACITY                NO.       OPER.   NO.   PM-HRS/    CM-HRS/
                               UNITS       HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

0-10000 GAL. PER MIN.              6  .1127E 06     0  .3885E-01  .0000E 00  .0000E 00  .1678E 06  .4896E 05  .1000E 01  .1000E 01
OVER 100000 GAL. PER MIN.          3  .5420E 05     9  .8350E 00  .7273E 01  .6667E 01  .5607E 04  .3815E 04  .9988E 00  .8610E 00
OVERALL STATISTICS                 9  .1669E 06     9  .1079E 00  .7871E 00  .6667E 01  .1727E 05  .1175E 05  .9996E 00  .9549E 00


        BROAD CLASSIFICATION                       GENERIC GROUPS                      APPLICATION
        PUMPS(WITHOUT MOTOR)                  OPEN IMPELLER CENTRIFUGAL PUMP       RETURN ACTIVATED SLUDGE HANDLING
  SIZE- CAPACITY                NO.       OPER.   NO.   PM-HRS/    CM-HRS/
                               UNITS       HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

0-10000 GAL. PER MIN.             27  .1023E 07    28  .1745E-02  .1028E 00  .6786E 01  .3569E 05  .2835E 05  .9998E 00  .9998E 00
OVERALL STATISTICS                27  .1023E 07    28  .1745E-02  .1028E 00  .6786E 01  .3569E 05  .2835E 05  .9998E 00  .9998E 00


        BROAD CLASSIFICATION                       GENERIC GROUPS                      APPLICATION
        PUMPS(WITHOUT MOTOR)                    PROPELLER,AXIAL FLOW                        INTERMEDIATE WASTEWATER PUMPING
  SIZE- CAPACITY                NO.       OPER.   NO.   PM-HRS/    CM-HRS/
                               UNITS       HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

20001-100000 GAL. PER MIN.         5  .8586E 06     4  .1020E-02  .7836E 00  .4000E 02  .1838E 06  .1074E 06  .9998E 00  .9979E 00
OVER 100000 GAL. PER MIN.          2  .3613E 05     5  .5455E 01  .4836E 02  .4000E 01  .6374E 04  .3896E 04  .9994E 00  .9908E 00
OVERALL STATISTICS                 7  .8947E 06     9  .6364E-01  .1095E 01  .2000E 02  .9255E 05  .6298E 05  .9998E 00  .9976E 00


        BROAD CLASSIFICATION                       GENERIC GROUPS                      APPLICATION
        PUMPS(WITHOUT MOTOR)                    PROPELLER,AXIAL FLOW                        RETURN ACTIVATED SLUDGE HANDLING
  SIZE- CAPACITY                NO.       OPER.   NO.   PM-HRS/    CM-HRS/
                               UNITS       HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

10001-20000 GAL. PER MIN.         20  .3613E 06     0  .1212E-01  .0000E 00  .0000E 00  .5377E 06  .1569E 06  .1000E 01  .1000E 01
OVER 100000 GAL. PER MIN.          8  .1445E 06     0  .3030E-01  .0000E 00  .0000E 00  .2151E 06  .6278E 05  .1000E 01  .1000E 01
OVERALL STATISTICS                28  .5059E 06     0  .8658E-02  .0000E 00  .0000E 00  .7528E 06  .2197E 06  .1000E 01  .1000E 01


        BROAD CLASSIFICATION                       GENERIC GROUPS                      APPLICATION
        PUMPS(WITHOUT MOTOR)                    PROPELLER,AXIAL FLOW                        RECIRCULATION PUMPING
  SIZE- CAPACITY                NO.       OPER.   NO.   PM-HRS/    CM-HRS/
                               UNITS       HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO
```

TABLE 3. EXCERPTS FROM WASTEWATER TREATMENT PLANT REPORT - RELIABILITY STATISTICS BY GENERIC GROUP/APPLICATION SIZE RANGE BY PLANT

```
PLANT NUMBER IS  1
        BROAD CLASSIFICATION                    GENERIC GROUPS                          APPLICATION
        PUMPS(WITHOUT MOTOR)                UPEN IMPELLER CENTRIFUGAL PUMP        RETURN ACTIVATED SLUDGE HANDLING
   SIZE- CAPACITY                 NO.        OPER.   NO.   PM-HRS/    CM-HRS/
                                 UNITS        HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

0-10000 GAL. PER MIN.              16  .8585E 06    27  .3189E-03  .1971E 00  .6815E 01  .3104E 05  .2456E 05  .9998E 00  .9998E 00
OVERALL STATISTICS                 16  .8585E 06    27  .3189E-03  .1971E 00  .6815E 01  .3104E 05  .2456E 05  .9998E 00  .9998E 00


PLANT NUMBER IS  1
        BROAD CLASSIFICATION                    GENERIC GROUPS                          APPLICATION
        POWER TRANSMISSION                      PARALLEL SHAFT                    OXYGEN GENERATION/STORAGE
   SIZE- CAPACITY                 NO.        OPER.   NO.   PM-HRS/    CM-HRS/
                                 UNITS        HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

OVER 500 HORSEPOWER                 2  .2641E 05     0  .1658E 00  .0000E 00  .0000E 00  .3930E 05  .1147E 05  .1000E 01  .1000E 01
OVERALL STATISTICS                  2  .2641E 05     0  .1658E 00  .0000E 00  .0000E 00  .3930E 05  .1147E 05  .1000E 01  .1000E 01


PLANT NUMBER IS  1
        BROAD CLASSIFICATION                    GENERIC GROUPS                          APPLICATION
        POWER TRANSMISSION                      PARALLEL SHAFT                    DISSOLVED AIR PRODUCTION
   SIZE- CAPACITY                 NO.        OPER.   NO.   PM-HRS/    CM-HRS/
                                 UNITS        HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

OVER 500 HORSEPOWER                 6  .4709E 06     2  .6201E-02  .5953E 00  .3200E 02  .1763E 06  .8847E 05  .9998E 00  .9996E 00
OVERALL STATISTICS                  6  .4709E 06     2  .6201E-02  .5953E 00  .3200E 02  .1763E 06  .8847E 05  .9998E 00  .9996E 00


PLANT NUMBER IS  1
        BROAD CLASSIFICATION                    GENERIC GROUPS                          APPLICATION
        POWER TRANSMISSION                    RIGHT-ANGLE SHAFT                   CLARIFIER CIRCULAR CENTER DRIVE
   SIZE- CAPACITY                 NO.        OPER.   NO.   PM-HRS/    CM-HRS/
                                 UNITS        HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

0-1 HORSEPOWER                     12  .1275E 07   176  .1718E-02  .1391E 00  .1375E 01  .7219E 04  .6563E 04  .9998E 00  .9998E 00
OVERALL STATISTICS                 12  .1275E 07   176  .1718E-02  .1391E 00  .1375E 01  .7219E 04  .6563E 04  .9998E 00  .9998E 00


PLANT NUMBER IS  1
        BROAD CLASSIFICATION                    GENERIC GROUPS                          APPLICATION
        POWER TRANSMISSION                      GEAR BOX                          CLARIFIER CIRCULAR CENTER DRIVE
   SIZE- CAPACITY                 NO.        OPER.   NO.   PM-HRS/    CM-HRS/
                                 UNITS        HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO

0-1 HORSEPOWER                      8  .8499E 06    21  .0000E 00  .2512E 00  .6190E 01  .3924E 05  .3016E 05  .9998E 00  .9997E 00
OVERALL STATISTICS                  8  .8499E 06    21  .0000E 00  .2512E 00  .6190E 01  .3924E 05  .3016E 05  .9998E 00  .9997E 00


PLANT NUMBER IS  1
        BROAD CLASSIFICATION                    GENERIC GROUPS                          APPLICATION
        MOTORS                                  MULTI PHASE                       CLARIFIER CIRCULAR CENTER DRIVE
   SIZE- CAPACITY                 NO.        OPER.   NO.   PM-HRS/    CM-HRS/
                                 UNITS        HRS.  FAIL. UNIT/YEAR  UNIT/YEAR     MTTR       MTBF      90% CL      AVI        AVO
```

TABLE 4. EXCERPTS FROM WWTP REPORT-FAILURES BY SUBCOMPONENT BY SIZE RANGE

```
           BROAD CLASSIFICATION                              GENERIC GROUPS                             APPLICATION
           PUMPS(WITHOUT MOTOR)                       OPEN IMPELLER CENTRIFUGAL PUMP               RAW WASTEWATER PUMPING
SUB.COMP.    SIZE   RANGE   CODES

 CODES     00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25     TOTALS
   0        0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
   1        0  0  1  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          2
   2        0  0 15  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0         15
   3        0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
   8        0  0  2  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          3
   9        0  0  0  0 14  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0         14
  12        0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  23        0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  24        0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  26        0  0  0  0  5  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          5
  39        0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  42        0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  45        0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  55        0  0  1  0 13  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0         14
  62        0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
TOTALS      0  0 22  3 37  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0         62

           BROAD CLASSIFICATION                              GENERIC GROUPS                             APPLICATION
           PUMPS(WITHOUT MOTOR)                       OPEN IMPELLER CENTRIFUGAL PUMP               INTERMEDIATE WASTEWATER PUMPING
SUB.COMP.    SIZE   RANGE   CODES

 CODES     00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25     TOTALS
   0        0  0  0  0  2  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          2
  10        0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  12        0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  19        0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  38        0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
  49        0  0  0  0  4  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          4
  50        0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0          1
```

TABLE 5. EXCERPTS FROM WASTEWATER TREATMENT PLANT REPORT - NUMBER OF FAILURES BY SUBCOMPONENT BY SIZE RANGE FOR EACH PLANT

```
PLANT NUMBER IS  1
          BROAD CLASSIFICATION
          PUMPS(WITHOUT MOTOR)                                          GENERIC GROUPS                                      APPLICATION
SUB.COMP.   SIZE   RANGE   CODES                                        OPEN IMPELLER CENTRIFUGAL PUMP                      RETURN ACTIVATED SLUDGE HANDLING

  CODES     00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25   TOTALS
    0        0 20  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0       20
   11        0  2  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0        2
   23        0  5  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0        5
TOTALS       0 27  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0       27

PLANT NUMBER IS  1
          BROAD CLASSIFICATION
          POWER TRANSMISSION                                            GENERIC GROUPS                                      APPLICATION
SUB.COMP.   SIZE   RANGE   CODES                                        PARALLEL SHAFT                                      OXYGEN GENERATION/STORAGE

  CODES     00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25   TOTALS
    0        0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0        0
TOTALS       0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0        0

PLANT NUMBER IS  1
          BROAD CLASSIFICATION
          POWER TRANSMISSION                                            GENERIC GROUPS                                      APPLICATION
SUB.COMP.   SIZE   RANGE   CODES                                        PARALLEL SHAFT                                      DISSOLVED AIR PRODUCTION

  CODES     00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25   TOTALS
    0        0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0        0
   23        0  0  0  0  0  0  0  0  0  0  2  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0        2
TOTALS       0  0  0  0  0  0  0  0  0  0  2  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0        2

PLANT NUMBER IS  1
          BROAD CLASSIFICATION
          POWER TRANSMISSION                                            GENERIC GROUPS                                      APPLICATION
SUB.COMP.   SIZE   RANGE   CODES                                        RIGHT-ANGLE SHAFT                                   CLARIFIER CIRCULAR CENTER DRIVE

  CODES     00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25   TOTALS
    4        0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0        1
   12        0  0  0  0  0127  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0      127
   13        0  0  0  0  0  3  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0        3
   25        0  0  0  0  0 44  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0       44
```

TABLE 6. EXCERPTS FROM WWTP REPORT-RELIABILITY OF SLUDGE PROCESSES

PROCESS	OP. HOURS	NO. FAIL	MTBF	90% CL	AVAIL
SLUDGE PROCESS EXTERNAL TO WW TREAT. PROCESS	.780E 06	400	.195E 04	.183E 04	.997E 00
ANAEROBIC DIGESTION	.678E 06	40	.167E 05	.137E 05	.100E 01
INCINERATION	.374E 06	454	.824E 03	.776E 03	.723E 00
SLUDGE THICKENING DAF	.406E 06	702	.577E 03	.550E 03	.994E 00
VACUUM FILTER	.697E 06	1150	.606E 03	.583E 03	.931E 00

TABLE 7. EXCERPTS FROM WWTP REPORT-RELIABILITY OF SLUDGE PROCESSES BY PLANT

```
PLANT NUMBER IS   1

        PROCESS                                   OP. HOURS   NO. FAIL     MTBF        90% CL       AVAIL

SLUDGE PROCESS EXTERNAL TO WW TREAT. PROCESS      .461E 06      319      .144E 04    .134E 04    .999E 00
SLUDGE THICKENING DAF                             .406E 06      702      .577E 03    .550E 03    .994E 00
VACUUM FILTER                                     .191E 06      754      .253E 03    .241E 03    .963E 00

PLANT NUMBER IS   3

        PROCESS                                   OP. HOURS   NO. FAIL     MTBF        90% CL       AVAIL

SLUDGE PROCESS EXTERNAL TO WW TREAT. PROCESS      .903E 05       18      .484E 04    .365E 04    .984E 00
INCINERATION                                      .374E 06      454      .824E 03    .776E 03    .723E 00
VACUUM FILTER                                     .506E 06      396      .128E 04    .120E 04    .919E 00

PLANT NUMBER IS   5

        PROCESS                                   OP. HOURS   NO. FAIL     MTBF        90% CL       AVAIL

SLUDGE PROCESS EXTERNAL TO WW TREAT. PROCESS      .229E 06       63      .359E 04    .307E 04    .998E 00
ANAEROBIC DIGESTION                               .678E 06       40      .167E 05    .137E 05    .100E 01
```

(3) NWAP indicates within or across plants for reports. NWAP is set to 1 for within plants and to 2 for across plants.

(4) NSRT indicates the type (or sort) of report which is desired from the wastewater treatment process data when NWWS is set to 1. When NSRT is set to 1, the first report type described in section 4.0 is generated. When NSRT is set to 3, the data is sorted in the order specified in the NS1 and NS2 sort vectors.

(5) NSS is the number of fields to be sorted (when NWWS=1 and NSRT=3).

(6) NS1(I) indicates the i^{th} field in the sort order (up to 6 fields can be specified from the 28 fields in the data record) when NWWS=1 and NSRT=3.

(7) NS2(I) indicates whether the field specified in NS1(I) is to be sorted in ascending or descending order. NS2(I) is set to 0 (or left blank) for ascending, and to 1 for descending order.

(8) NPRT allows a print-out option on the sorted data for the first two types of reports. If NPRT is set to 0 (or left blank) no print out of the sorted data records is made. When NPRT is set to 1, a print out is made.

The first card of the control data deck contains NPC, the number of reports to be generated on a single run. Each of the next NPC cards contain the set of values for the other seven parameters which describe the report desired.

The format and card column (all right justified) for each of the parameters is given in Table 8. The input data deck must be read onto a file named "WRAPDATA."

The WRAPDATA file required to generate the report types shown in Tables

TABLE 8. WRAPDATA CARD INPUT DESCRIPTION

Field Columns	Description	Program Symbol	FORTRAN Format
	REPORT COUNTER CARD		
1-5	Number of Reports for Computer Run	NPC	I5
	REPORT DESCRIPTION CARD		
1-4	Wastewater or Sludge Treatment Processes	NWWS	I4
5-8	Within or Across Plants	NWAP	I4
9-12	Type of Wastewater Treatment Report Desired	NSRT	I4
13-16	Number of Fields to be Sorted	NSS	I4
17-40	Sort Vector	NS1(I) $1 \leq I \leq 6$	6I4
41-64	Ascending or Descending Sort	NS2(I) $1 \leq I \leq 6$	6I4
65-68	Print Option	NPRT	I4

2, 3, 4, 5, 6 and 7 and a sort of the wastewater treatment process data in ascending order by broad classification, generic group, application, size, record number and plant number is shown in Table 9.

COMPUTER PROGRAM DOCUMENTATION

Fortran Code and Flow Charts

WRAP is written in FORTRAN V and is presently operational on a Data General Minicomputer. The program consists of the main program (WRAP), and eight subroutines. The data base file is labelled "DATA2" and the report control file is labelled "WRAPDATA."

Detailed flow charts for the main program and subroutines ACHMBE, MANTBE, MERGBE, MTBFBE and SORTBE are given in Appendix E-2. Flow charts are not included for subroutines WRTRBE, WRT5BE and WRT8BE for these subroutines are used mainly for formatting the various reports.

A complete listing of the FORTRAN code for the main program and all subroutines is given in Appendix E-3. A brief description of how the statistics are calculated from the data is given in the following section.

Subroutine Functions and Algorithms

Reliability and Maintainability Statistics for Wastewater Treatment Processes (see Table 2)--

The number of units for the particular component classification group is calculated by summing across the applicable data records.

The operating hours are calculated as follows. The total number of hours between the date the data was gathered and the installation date is calculated for each data record. This total is multiplied by the percentage of time the unit was operating (as reported in data field 13). These values are summed across the applicable data records.

TABLE 9. INPUT DATA FOR REPORT GENERATION EXAMPLE

80 COLUMN DATA FORM

DATE

PAGE OF

EXTENSION NO.

☐ ☐

☐ ☐

☐ KEYPUNCH, VERIFY, LIST, AND RETURN TO REQUESTER AT:

☐ KEYPUNCH, VERIFY, LIST, AND ADD TO REQUESTER'S DECK NO.

RUN AND RETURN TO REQUESTER AT:

REQUESTOR	PROGRAM NO.	DIVISION	COST CENTER	E.O./Q.O./W.O./ACCOUNT NO.

	1				5					10					15					20					25					30					35					40
8																																							
01				7																																			
02				1				2				1																											
03				1				1				1																											
04				1				2				2																											
05				1				1				2																											
06				2				2																															
07				2				1																															
08				1								3				6				5				6				7				8				2				1
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29																																							
30																																							

NOTE: + MEANS 12 OVERPUNCH; — MEANS 11 OVERPUNCH
+ OR — IN 8 ROW MEANS OVERPUNCH IN EVERY CARD

DP-16

The number of failures is calculated by summing on data field 14.

The preventative maintenance hours per unit year (PM-HRS./UNIT/YEAR) is calculated by summing the preventative maintenance manhours and then dividing this sum by the product of the number of units and the operating years (operating hours divided by 8,760).

The corrective maintenance hours per unit year are calculated according to the same logic as the PM-HRS/UNIT/YR.

The mean time to repair (MTTR) is calculated by summing the active corrective repair times reported in field 28, and dividing by the number of failures.

The point estimate of the mean time between failures (MTBF) is calculated by dividing twice the operating hours by the 50th percentile value of the Chi-Square distribution with 2r+2 degrees of freedom, where r is the number of failures.

The 90% confidence limit (90%CL) on the point estimate is calculated by dividing twice the operating hours by the 10th percentile value of the Chi-Square distribution with 2r+2 degrees of freedom.

The inherent availability (AVI) is calculated by the formula:

$$AVI = 1/(1+MTTR/MTBF).$$

The operating availability (AVO) is calculated by the formula:

$$AVO = (TH-THD)/TH ,$$

where,

TH is the total scheduled operating hours; and

THD is the total calendar time hours calculated by summing on field 17.

Failures by Subcomponent Code by Size Range Code (see Table 4)--

The number of failures by subcomponent code for each grouping of size-capacity range, application, generic group and broad classification is obtained simply by summing the number of failures reported for that grouping.

Sludge Treatment Process Report (see Table 6)--

The operating hours, number of failures, MTBF and 90% confidence limit on the MTBF are calculated in the same manner as for the wastewater treatment processes. The availability (AVAIL) is calculated by:

$$\text{AVAIL} = (\text{TH}-\text{DT})/\text{TH} ,$$

where,

TH is the total scheduled operating hours (same as in wastewater treatment), and

DT is the total downtime of the process obtained by summing on field 25.

APPENDIX E-1

DATA2 FILE

```
+444444444444444444444444444444444           .444444444444444444444444444444444444

                     $   $  $$$$   $$$$              $    $$$$$  $$$$$     $     $$$
                     $   $  $   $  $   $            $$        $  $        $$    $   $
                     $   $  $   $  $   $           $ $       $   $$$$    $ $        $
                     $   $  $$$$   $$$$              $      $        $  $  $      $$
                     $   $  $   $  $                 $     $         $  $$$$$    $
                      $ $   $   $  $                 $     $     $   $     $    $
                       $    $$$$   $      $$$$$  $$$$$     $      $$$      $    $$$$$

                                 DEST=VBP←175426003  USER=VBP←175426003  QUEUE=LP
                                    SEQ=9586  QPRI=191  LPP=66  CPL=132  COPIES=1

                                                  CREATED:  11-JUL-80  12:46:34
                                                 ENQUEUED:  11-JUL-80  12:50:26
                                                 PRINTING:  11-JUL-80  12:52:07

                                                  PATH=:UDD:VBP←175426003:DATA2

                                                $$$$     $    $$$$$    $     $$$
                                                $   $   $ $     $     $ $   $   $
                                                $   $  $   $    $    $   $      $
                                                $   $  $   $    $    $   $    $$
                                                $   $  $$$$$    $    $$$$$   $
                                                $   $  $   $    $    $   $  $
                                                $$$$   $   $    $    $   $  $$$$$
+44444444444444444444444444444444444444444444444444444444444444444444444444444444



                                                SOUTHWEST RESEARCH INST. DIV 17

                                                         AOS REV 03.04
                                                      AOS XLPT REV 03.04
```

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091311 01 01 03 050202090420101772501000804041202022018 04 02 00000 12780060
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050046 03 06 01 0109300100000015909040000000000000000015 00 00 00032 09790008
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050083 03 01 07 070104070000200339999000000000000000000 00 00 00000 09790000
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010005 01 03 03 030211080000110665001000000031204 00 16 03 02          0179   7
010005 01 03 07 070111080000110665005000000021202 00 00 02 02          0179  20
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010007 01 03 01 010911010000110665099           12    15    01          0179   0
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010007 01 03 07 070111080370110665004000000021202 00 00 01 02          0179  10
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010032 01 04 02 020306050230110669903000001010102 00 10 01 02           0179   3
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010032 01 04 02 020806050100110669901000003030101 00 10 01 02           0179   4
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010032 01 04 07 070106050000110669999                00                 0179   0
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010035 01 04 02 020806050000110669901000000020101 00 10 03 02           0179   1
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010043    12                 08675050                11             422 0179   0
010043    12                 0867 078                11               0 0179   0
010044    12                 05675050                11             397 0179   0
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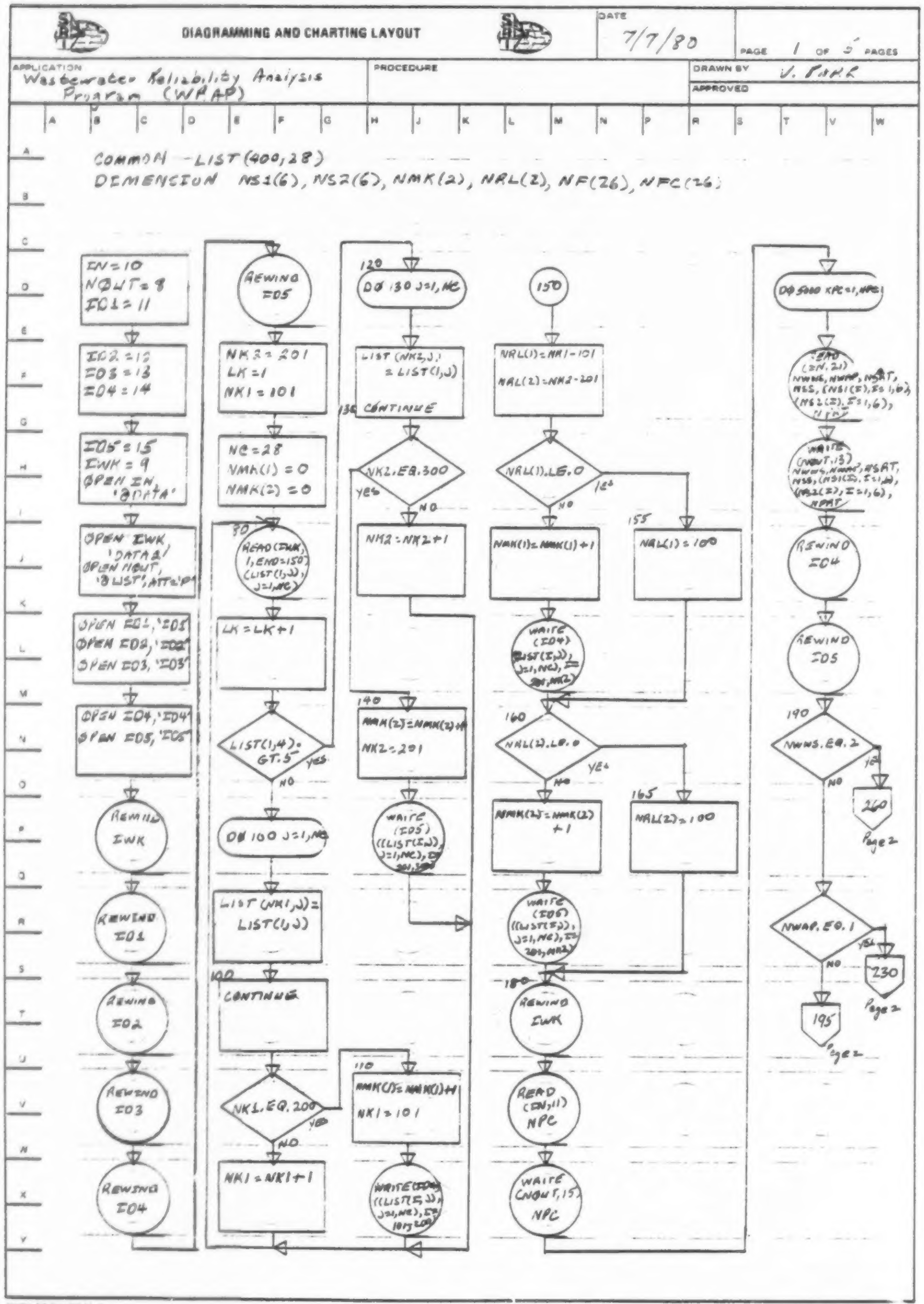
APPENDIX E-2

WRAP PROGRAM FLOW CHARTS



DIAGRAMMING AND CHARTING LAYOUT

DATE 7/7/80

PAGE 1 OF 5 PAGES

APPLICATION Wastewater Reliability Analysis Program (WRAP)

PROCEDURE

DRAWN BY V. Pahl

APPROVED

```
COMMON -LIST(400,28)
DIMENSION NS1(6),NS2(6),NMK(2),NRL(2),NF(26),NFC(26)
```

A B C D E F G H J K L M N P R S T V W
A B C D E F G H J K L M N O P Q R S T U V W X Y
IN=10
NØUT=8
IO1=11
IO2=12
IO3=13
IO4=14
IO5=15
IWK=9
ØPEN IN, 'ØDATA'
OPEN IWK, 'DATA2'
ØPEN NØUT, 'ØLIST', ATT='P'
OPEN IO1, 'IO1'
ØPEN IO2, 'IO2'
ØPEN IO3, 'IO3'
ØPEN IO4, 'IO4'
ØPEN IO5, 'IO5'
REWIND IWK
REWIND IO1
REWIND IO2
REWIND IO3
REWIND IO4
REWIND IO5
NK2=201
LK=1
NK1=101
NC=28
NMK(1)=0
NMK(2)=0
80
READ(IWK, 1,END=150) (LIST(1,J), J=1,NC)
LK=LK+1
LIST(1,4).GT.5
YES
NO
DØ 100 J=1,NC
LIST(NK1,J)=LIST(1,J)
100
CONTINUE
NK1.EQ.200
YES
NO
NK1=NK1+1
110
NMK(1)=NMK(1)+1
NK1=101
WRITE(IO4) ((LIST(I,J), J=1,NC), I=101,200)
120
DØ 130 J=1,NC
LIST(NK2,J) = LIST(1,J)
130 CONTINUE
NK2.EQ.300
YES
NO
NK2=NK2+1
140
NMK(2)=NMK(2)+1
NK2=201
WRITE (IO5) ((LIST(I,J), J=1,NC), I= 201,300)
150
NRL(1)=NK1-101
NRL(2)=NK2-201
NRL(1).LE.0
YES
NO
NMK(1)=NMK(1)+1
155
NRL(1)=100
WRITE (IO4) (LIST(I,J), J=1,NC), I= 201,NK2)
160
NRL(2).LE.0
YES
NO
NMK(2)=NMK(2) +1
165
NRL(2)=100
WRITE (IO5) ((LIST(I,J)), J=1,NC), I= 201,NK2)
180
REWIND IWK
READ (IN,11) NPC
WRITE (NØUT,15) NPC
DØ 5000 KPC=1,NPC
READ (IN,21) NWWS, NWAP, NSAT, NSS, (NS1(I),I=1,6), (NS2(I),I=1,6), NPAT
WRITE (NØUT,13) NWWS,NWAP,NSAT, NSS,(NS1(I),I=1,6), (NS2(I),I=1,6), NPAT
REWIND IO4
REWIND IO5
190
NWWS.EQ.2
YES
260
Page 2
NO
NWAP.EQ.1
YES
230
Page 2
NO
195
Page 2

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DIAGRAMMING AND CHARTING LAYOUT

DATE 7/7/70

PAGE 2 OF 5 PAGES

APPLICATION WRAP

PROCEDURE

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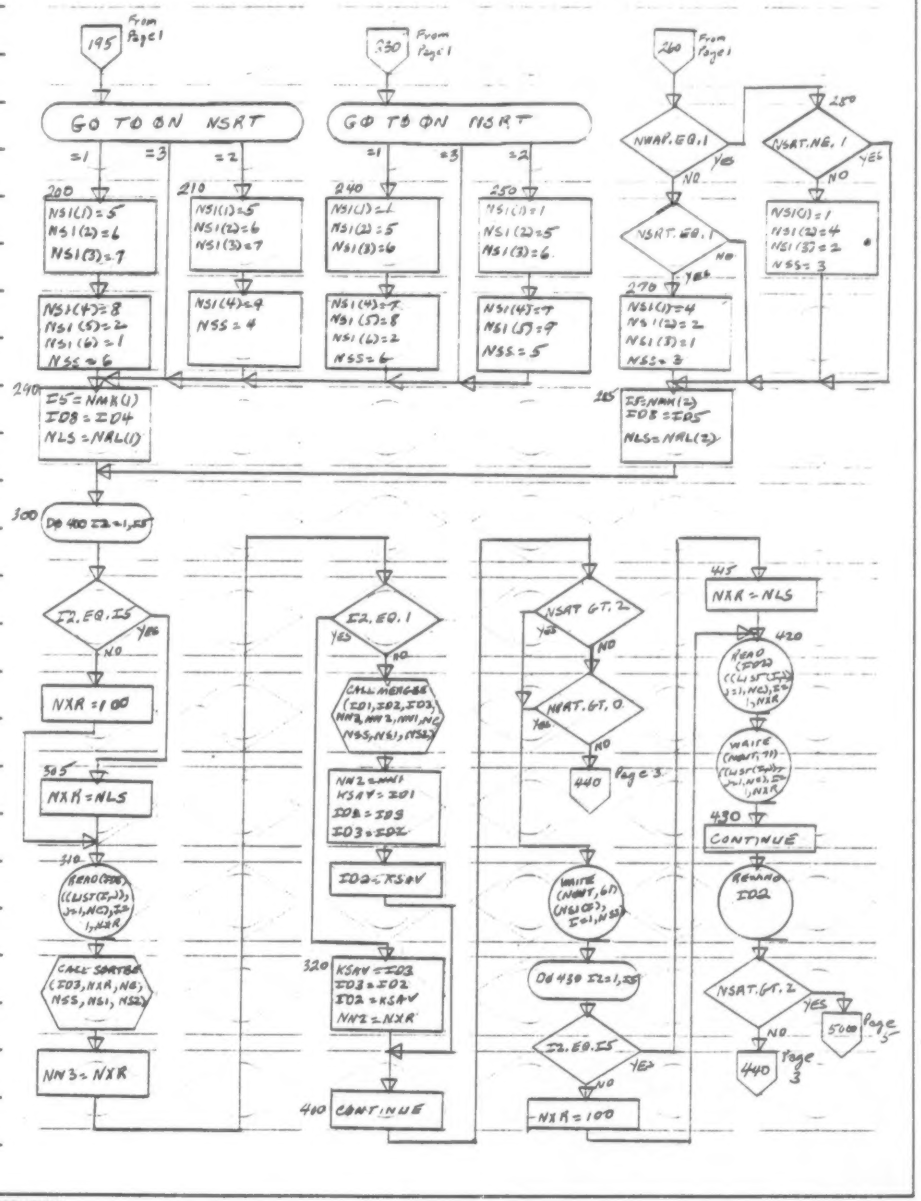

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I
O
Q
U
X
Y
195
From Page 1
GO TO ON NSRT
=1
=3
=2
200
NSI(1)=5
NSI(2)=6
NSI(3)=7
NSI(4)=8
NSI(5)=2
NSI(6)=1
NSS=6
210
NSI(1)=5
NSI(2)=6
NSI(3)=7
NSI(4)=9
NSS=4
230
From Page 1
GO TO ON NSRT
=1
=3
=2
240
NSI(1)=1
NSI(2)=5
NSI(3)=6
NSI(4)=7
NSI(5)=8
NSI(6)=2
NSS=6
250
NSI(1)=1
NSI(2)=5
NSI(3)=6.
NSI(4)=7
NSI(5)=9
NSS=5
260
From Page 1
NWAP.EQ.1
YES
NO
NSRT.EQ.1
NO
YES
270
NSI(1)=4
NSI(2)=2
NSI(3)=1
NSS=3
280
NSRT.NE.1
YES
NO
NSI(1)=1
NSI(2)=4
NSI(3)=2
NSS=3
290
I5=NMK(1)
ID8=ID4
NLS=NRL(1)
285
I5=NMK(2)
ID8=ID5
NLS=NRL(2)
300
DO 400 I2=1,I5
I2.EQ.I5
YES
NO
NXR=100
305
NXR=NLS
310
READ(ID8)((LIST(I,J)),J=1,NC),I=1,NXR
CALL SORTBE(ID3,NXR,NC,NSS,NS1,NS2)
NN3=NXR
I2.EQ.1
YES
NO
CALL MERGES(ID1,ID2,ID3,NN3,NN2,NN1,NC,NSS,NS1,NS2)
NN2=NN1
KSAV=ID1
ID1=ID3
ID3=ID2
ID2=KSAV
320
KSAV=ID3
ID3=ID2
ID2=KSAV
NN2=NXR
410
CONTINUE
NSAT GT.2
YES
NO
NEAT.GT.0
YES
NO
440
Page 3
WRITE(NOUT,61)(NS1(I),I=1,NSS)
DO 430 I2=1,I5
I2.EQ.I5
YES
NO
NXR=100
415
NXR=NLS
420
READ(ID2)((LIST(I,J)),J=1,NC),I=1,NXR
WRITE(NOUT,71)((LIST(I,J)),J=1,NC),I=1,NXR
430
CONTINUE
REWIND ID2
NSAT.GT.2
YES
5000
Page 5
NO
440
Page 3

SWRI FORM 55-51-0

DIAGRAMMING AND CHARTING LAYOUT

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APPLICATION WRAP

PROCEDURE

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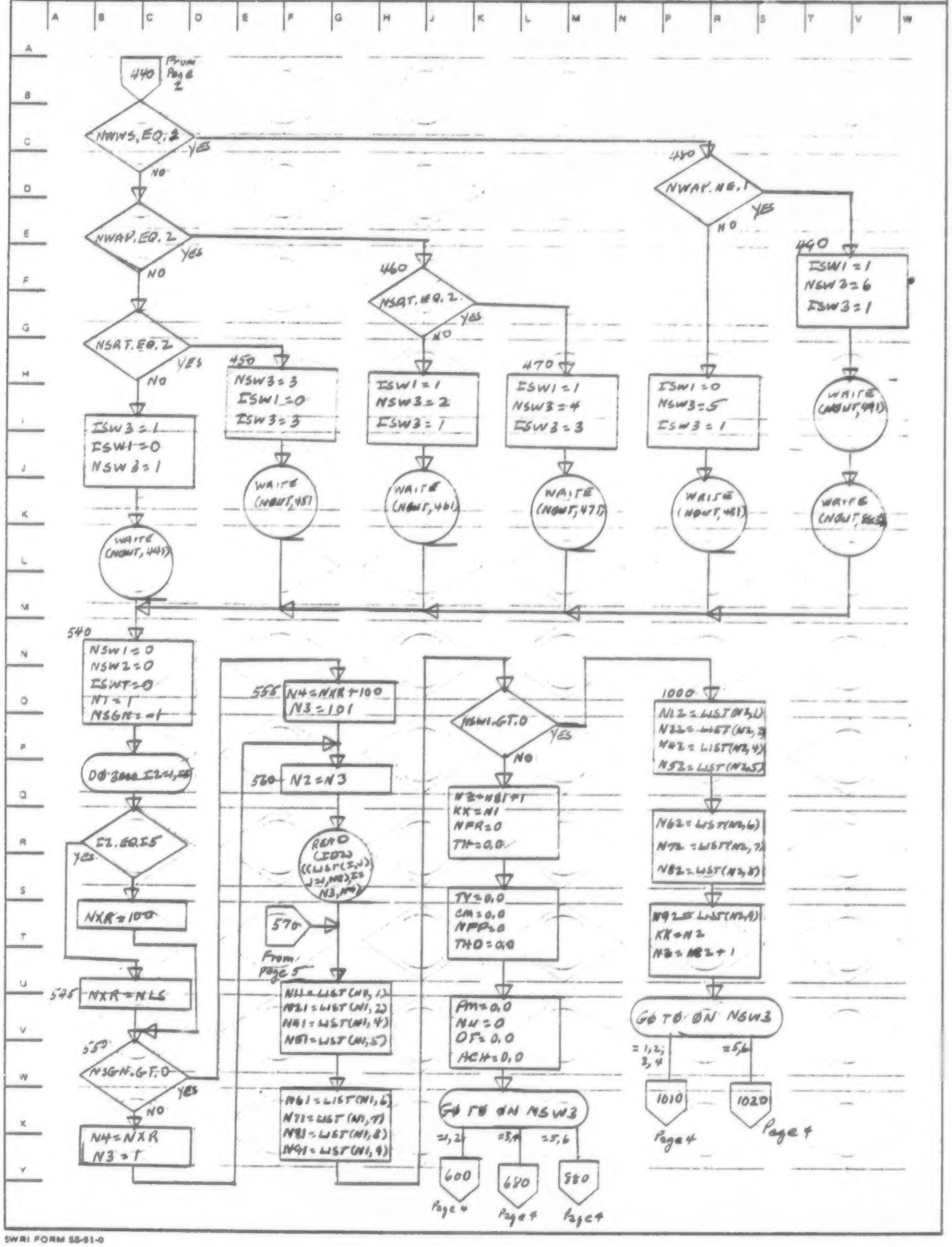
A
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K
L
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N
P
R
S
T
V
W
440
From Page 2
NWWS.EQ.2
YES
NO
480
NWAP.NE.1
YES
NO
NWAP.EQ.2
YES
NO
460
NSAT.EQ.2
YES
NO
490
ISW1=1
NSW3=6
ISW3=1
NSAT.EQ.2
YES
NO
450
NSW3=3
ISW1=0
ISW3=3
ISW1=1
NSW3=2
ISW3=1
470
ISW1=1
NSW3=4
ISW3=3
ISW1=0
NSW3=5
ISW3=1
WRITE (NOUT,491)
ISW3=1
ISW1=0
NSW3=1
WRITE (NOUT,451)
WRITE (NOUT,461)
WRITE (NOUT,471)
WRITE (NOUT,481)
WRITE (NOUT,
WRITE (NOUT,441)
540
NSW1=0
NSW2=0
ISWT=0
NT=1
NSGN=-1
555
N4=NXR+100
N3=101
NSW1.GT.0
YES
NO
1000
N12=LIST(N3,1)
N22=LIST(N2,
N42=LIST(N2,4)
N52=LIST(N2,5)
DO 3000 I2=1,I5
560
N2=N3
N2=N81+1
KK=N1
NFR=0
TH=0.0
N62=LIST(N2,6)
N72=LIST(N2,7)
N82=LIST(N2,8)
I2.EQ.I5
YES
READ (IO2) ((LIST(I,J) J=1,N2),I=N3,N4)
TY=0.0
CM=0.0
NFP=0
THO=0.0
N92=LIST(N2,9)
KK=N2
N3=N82+1
NXR=100
570
From Page 5
545
NXR=NLS
N11=LIST(N1,1)
N21=LIST(N1,2)
N41=LIST(N1,4)
N51=LIST(N1,5)
AM=0.0
NU=0
OF=0.0
ACH=0.0
GO TO ON NSW3
=1,2;3,4
=5,6
1010
Page 4
1020
Page 4
550
NSGN.GT.0
YES
NO
N61=LIST(N1,6)
N71=LIST(N1,7)
N81=LIST(N1,8)
N91=LIST(N1,9)
GO TO ON NSW3
=1,2
=3,4
=5,6
N4=NXR
N3=1
600
Page 4
680
Page 4
880
Page 4

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DIAGRAMMING AND CHARTING LAYOUT

DATE 7/7/8?	PAGE 4 OF 5 PAGES
APPLICATION Y/FAP	PROCEDURE
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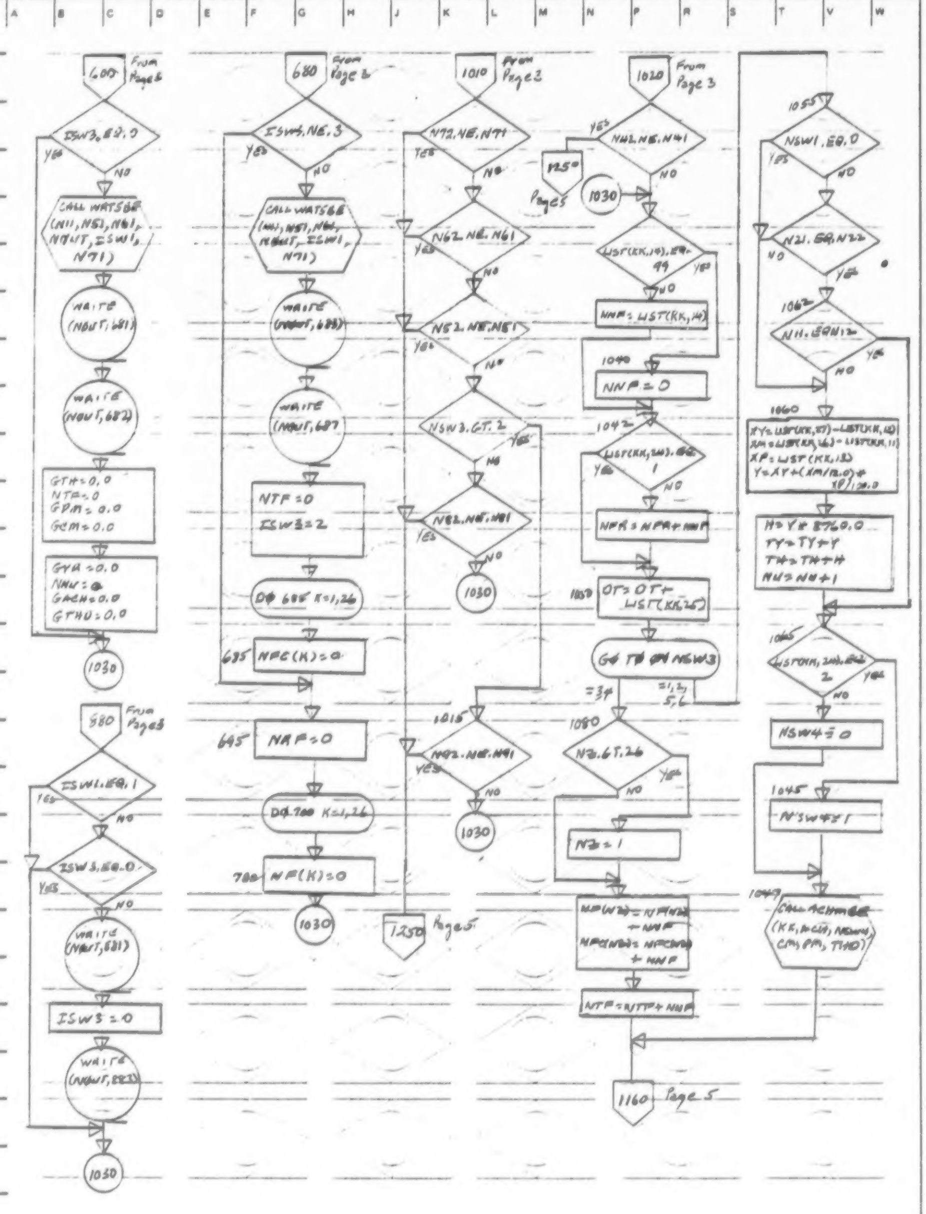
A B C D E F G H J K L M N P R S T V W
600 From Page 2
ISW3.EQ.0
YES
NO
CALL WATSBE (N11, N51, N61, NOUT, ISW1, N71)
WRITE (NOUT, 681)
WRITE (NOUT, 682)
GTH=0.0
NTF=0
GPM=0.0
GCM=0.0
GYA=0.0
NNU=0
GACH=0.0
GTHU=0.0
1030
580 From Page 3
ISW1.EQ.1
YES
NO
ISW3.EQ.0
YES
NO
WRITE (NOUT, 681)
ISW3=0
WRITE (NOUT, 683)
1030
680 From Page 2
ISW3.NE.3
YES
NO
CALL WATSBE (N11, N51, N61, NOUT, ISW1, N71)
WRITE (NOUT, 683)
WRITE (NOUT, 687)
NTF=0
ISW3=2
DO 695 K=1,26
695 NFC(K)=0
695 NRF=0
DO 700 K=1,26
700 NF(K)=0
1030
1010 From Page 3
N72.NE.N71
YES
NO
N62.NE.N61
YES
NO
N52.NE.N51
YES
NO
NSW3.GT.2
YES
NO
N82.NE.N81
YES
NO
1030
1015
N92.NE.N91
YES
NO
1030
1250 Page 5
1020 From Page 3
N42.NE.N41
YES
NO
1250 Page 5
1030
LIST(KK,14).EQ.99
YES
NO
NNF=LIST(KK,14)
1040
NNF=0
1042
LIST(KK,24).EQ.1
YES
NO
NFR=NFR+NNF
1050 OT=OT+LIST(KK,25)
GO TO ON NSW3
=1,2,5,6
=3,4
1080
N3.GT.26
YES
NO
N3=1
NF(N3)=NF(N3)+NNF
NFC(N3)=NFC(N3)+NNF
NTF=NTF+NNF
1160 Page 5
1055
NSW1.EQ.0
YES
NO
N21.EQ.N22
NO
YES
1062
N11.EQ.N12
YES
NO
1060
XY=LIST(KK,27)-LIST(KK,12)
XM=LIST(KK,16)-LIST(KK,11)
XP=LIST(KK,13)
Y=XY+(XM/12.0)+XP/120.0
H=Y*8760.0
TY=TY+Y
TH=TH+H
NU=NU+1
1065
LIST(KK,24).EQ.2
YES
NO
NSW4=0
1045
NSW4=1
1047
CALL ACHANGE (KK, NCH, NSW4, CM, PM, TMO)

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DIAGRAMMING AND CHARTING LAYOUT

DATE 7/7/80

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APPLICATION WRAP

PROCEDURE

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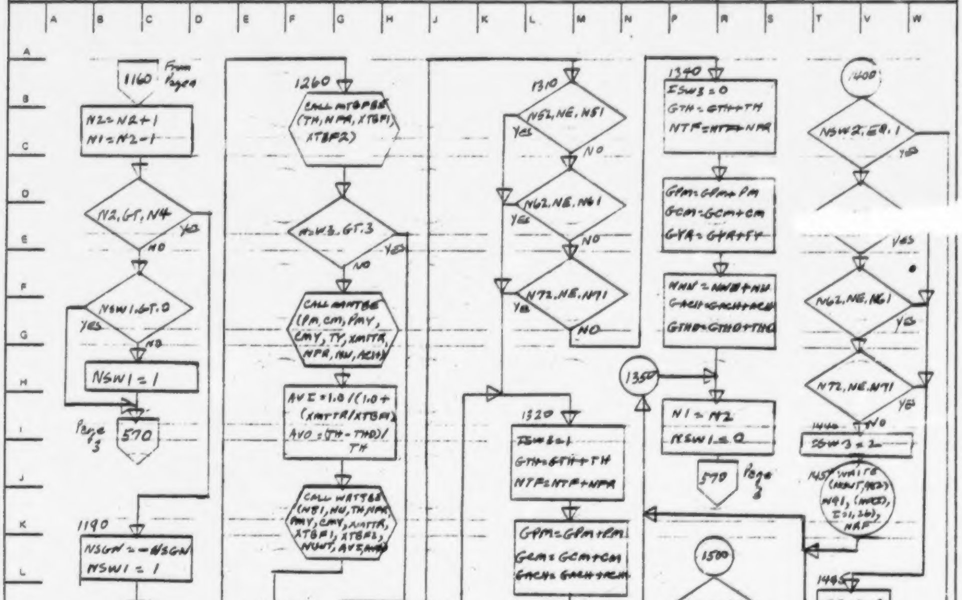
A B C D E F G H J K L M N P R S T V W
1160 From Page 4
N2=N2+1
N1=N2-1
N2.GT.N4
YES
NO
NSW1.GT.0
YES
NO
NSW1=1
Page 3
570
1190
NSGN=-NSGN
NSW1=1
IS.EQ.I2
YES
NO
3000
1200
NSW2=1
NSW3.GT.2
YES
NO
From Page 4
ISW3=1
1250
GO TO ON NSW3
=3,4
=1,2 5,6
1290
DO 1295 I=1,26
1295
NRF=NRF+NF(I)
1260
CALL MTGPBE (TH,NFR,XTBF1, XTBF2)
NSW3.GT.3
YES
NO
CALL MNTBE (PM,CM,PMY, CMY,TY,XMTTR, NFR,NU,ACH)
AVI=1.0/(1.0+ (XMTTR/XTBF1)
AVO=(TH-THD)/ TH
CALL WRTBE (NB1,NU,TH,NFR, PMY,CMY,XMTTR, XTBF1,XTBF2, NOUT,AVI,AVO)
1270
AV=(TH-DT)/ TH
CALL WRTABE (NG1,TH,NFR, XTBF1,XTBF2, AV,NOUT)
GO TO ON NSW3
=1,2
=3,4
=5,6
1500
1400
1300
NSW4.EQ.0
YES
NO
ISW3.EQ.1
YES
NO
1310
N52.NE.N51
YES
NO
N62.NE.N61
YES
NO
N72.NE.N71
YES
NO
1320
ISW3=1
GTH=GTH+TH
NTF=NTF+NFR
GPM=GPM+PM
GCM=GCM+CM
GACH=GACH+ACH
GYR=GYR+TY
GTHO=GTHO+THO
NWW=NWW+NU
CALL MTGPBE (GTH,NTF, XTBF1,XTBF2)
CALL MNTBE (GPM,GCM,PMY, CMY,GYR,XMTTR, NTF,NWW,GACH)
AVI=1.0/(1.0+ (XMTTR/XTBF1))
AVO=(GTH-GTHO) /GTH
WRITE (NOUT,1311) NWW,GTH,NTF,PMY CMY,XMTTR,XTBF1, XTBF2,AVI,AVO
NSW2.EQ.0
YES
NO
1340
ISW3=0
GTH=GTH+TH
NTF=NTF+NFR
GPM=GPM+PM
GCM=GCM+CM
GYR=GYR+TY
NWW=NWW+NU
GACH=GACH+ACH
GTHO=GTHO+THO
1350
N1=N2
NSW1=0
570 Page 3
1500
NSW1.EQ.1
YES
NO
ISW1.EQ.1
YES
NO
N11.EQ.N12
YES
NO
ISW3=1
1510
ISW3=0
1400
NSW2.EQ.1
YES
YES
N62.NE.N61
YES
N72.NE.N71
YES
NO
1440
ISW3=2
1457
WRITE (NOUT,982) N41,(NF(I), I=1,26), NRF
1495
ISW3=3
WRITE (NOUT,982) N41,(NF(I), I=1,26), NRF
WRITE (NOUT,983) (NF(I), I=1,26), NTF
1450
WRITE (NOUT,982) N41,(NF(I), I=1,26), NRF
WRITE (NOUT,983) (NF(I), I=1,26), NTF
3000
CONTINUE
5000
CONTINUE
From Page 2
STOP
END

SWRI FORM 55-61-0

DIAGRAMMING AND CHARTING LAYOUT

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APPLICATION WRAP - Subroutine ACHMBE

PROCEDURE

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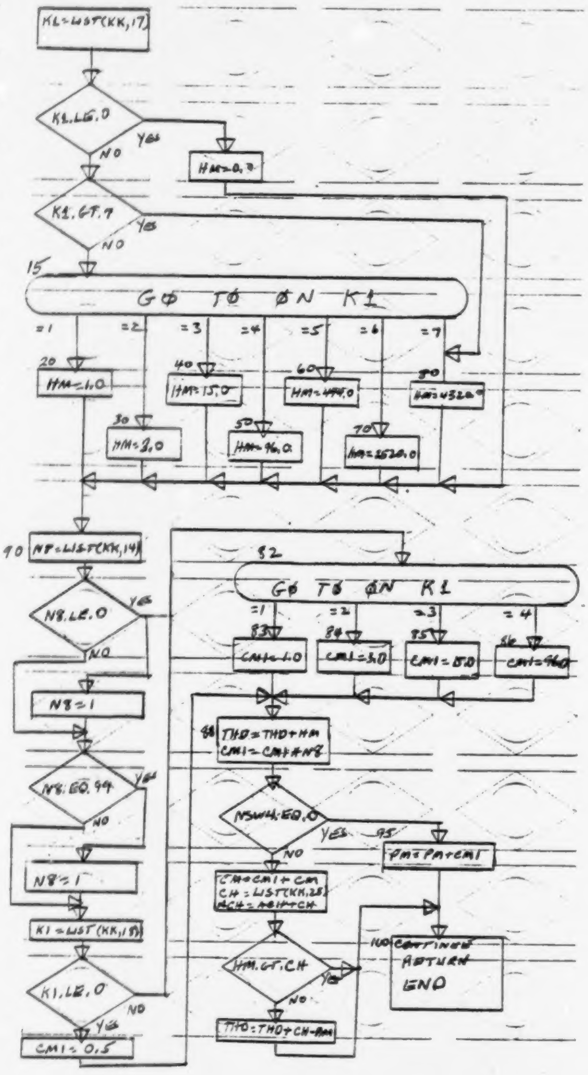
A B C D E F G H J K L M N P R S T V W

SUBROUTINE ACHMBE (KK, ACH, NSW4, CM, PM, THD)
COMMON LIST(400,28)



KL=LIST(KK,17)
K1.LE.0
YES
NO
HM=0.0
K1.GT.7
YES
NO
15
GO TO ON K1
=1
=2
=3
=4
=5
=6
=7
20
HM=1.0
30
HM=3.0
40
HM=15.0
50
HM=96.0
60
HM=494.0
70
HM=2520.0
80
HM=4320.0
90
N8=LIST(KK,14)
N8.LE.0
YES
NO
N8=1
N8.EQ.99
YES
NO
N8=1
K1=LIST(KK,18)
K1.LE.0
NO
YES
CM1=0.5
82
GO TO ON K1
=1
=2
=3
=4
83
CM1=1.0
84
CM1=3.0
85
CM1=15.0
86
CM1=96.0
88
THD=THD+HM
CM1=CM1*N8
NSW4.EQ.0
YES
NO
95
PM=PM+CM1
CM=CM1+CM
CH=LIST(KK,25)
ACH=ACH+CH
HM.GT.CH
YES
NO
THD=THD+CH-HM
100
CONTINUE
RETURN
END

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DIAGRAMMING AND CHARTING LAYOUT

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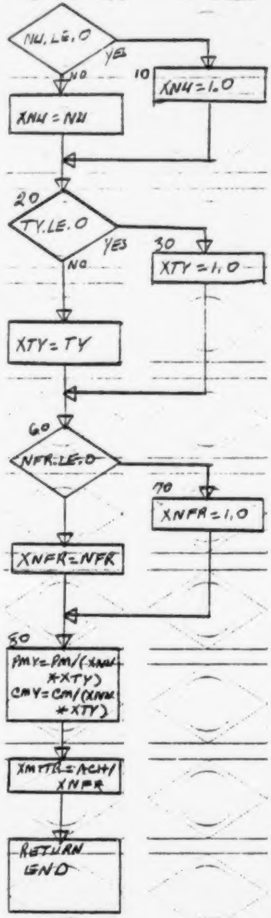
APPLICATION WRAP - Subroutine MANTBE	PROCEDURE	DRAWN BY V. Parr	APPROVED

SUBROUTINE MANTBE (PM, CM, PMY, TY, XMTTR, NFR, NU, ACH)
COMMON LIST (400,28)



NU.LE.0
YES
NO
10
XNU=1.0
XNU=NU
20
TY.LE.0
YES
NO
30
XTY=1.0
XTY=TY
60
NFR.LE.0
70
XNFR=1.0
XNFR=NFR
80
PMY=PM/(XNU*XTY)
CMY=CM/(XNU*XTY)
XMTTR=ACH/XNFR
RETURN
END

SWRI FORM 18-51-0

DIAGRAMMING AND CHARTING LAYOUT

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PAGE 1 OF 2 PAGES

APPLICATION WRAP - Subroutine MERGBE

PROCEDURE

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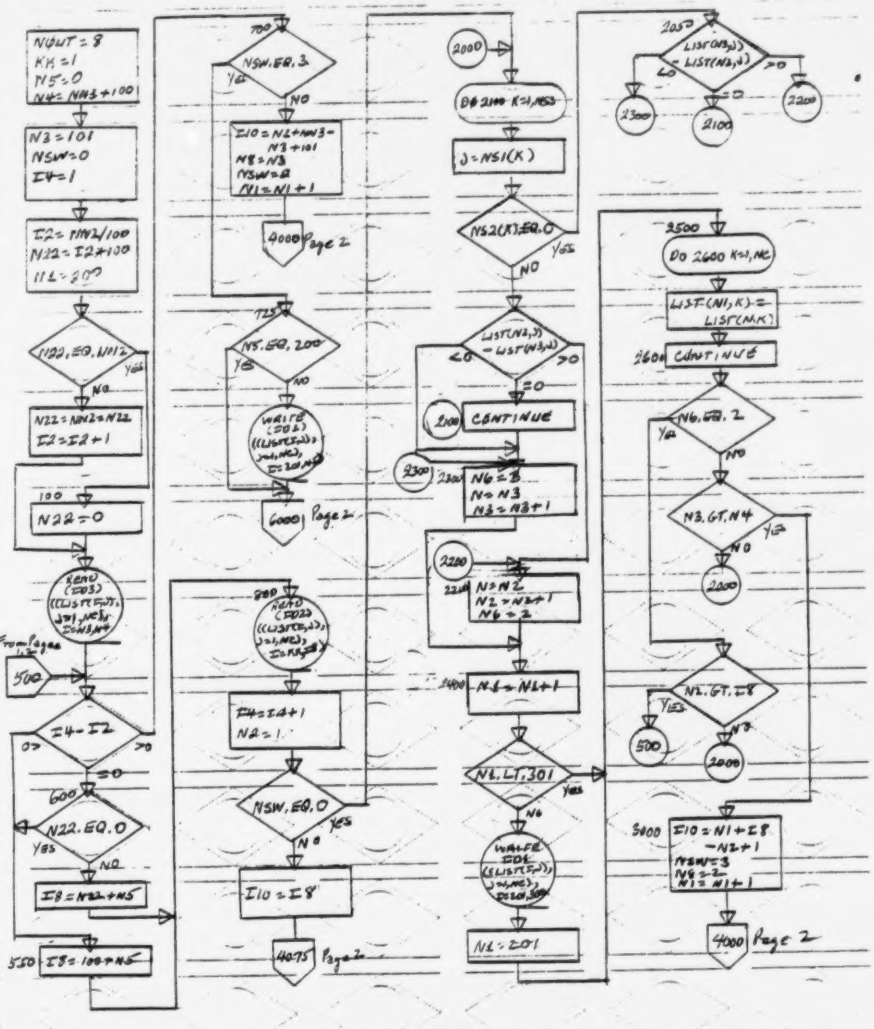
```
SUBROUTINE MERGBE (ID1,FD2,ID3,NN3,NN2,NN1,NC,NSS,NS1,NS2)
Common LIST(400.28)
DIMENSION NS1(6),NS2(6)
```


NOUT = 8
KK = 1
N5 = 0
N4 = NN3+100
N3 = 101
NSW = 0
I4 = 1
I2 = NN2/100
N22 = I2*100
N12 = 200
N22.EQ.NN2
YES
NO
N22 = NN2 - N22
I2 = I2+1
100
N22 = 0
READ (ID3) ((LIST(I,J), J=1,NC), I=N3,N4)
From Pages 1, 2
500
I4 - I2
<0
>0
=0
600
N22.EQ.0
YES
NO
I8 = N22+N5
550
I8 = 100+N5
700
NSW.EQ.3
YES
NO
I10 = N1+NN3-N3+101
N8 = N3
NSW = 2
N1 = N1+1
4000
Page 2
725
N5.EQ.200
YES
NO
WRITE (ID2) ((LIST(I,J), J=1,NC), I=201,N8)
6000
Page 2
800
READ (ID2) ((LIST(I,J), J=1,NC), I=KK,I8)
I4 = I4+1
N2 = 1
NSW.EQ.0
YES
NO
I10 = I8
4075
Page 2
2000
DO 2100 K=1,NSS
J = NS1(K)
NS2(K).EQ.0
YES
NO
LIST(N2,J) - LIST(N3,J)
<0
>0
=0
2100
CONTINUE
2300
2300
N6 = 3
N = N3
N3 = N3+1
2200
2200
N = N2
N2 = N2+1
N6 = 2
2400
N1 = N1+1
N1.LT.301
YES
NO
WRITE ID1 ((LIST(I,J), J=1,NC), I=201,300)
N1 = 201
2050
LIST(N3,J) - LIST(N2,J)
<0
=0
>0
2300
2100
2200
2500
DO 2600 K=1,NC
LIST(N1,K) = LIST(N,K)
2600
CONTINUE
N6.EQ.2
YES
NO
N3.GT.N4
YES
NO
2000
N2.GT.I8
YES
NO
500
2000
3000
I10 = N1+I8-N2+1
NSW = 3
N6 = 2
N1 = N1+1
4000
Page 2

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DIAGRAMMING AND CHARTING LAYOUT

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PAGE 2 OF 2 PAGES

APPLICATION MERGBE

PROCEDURE

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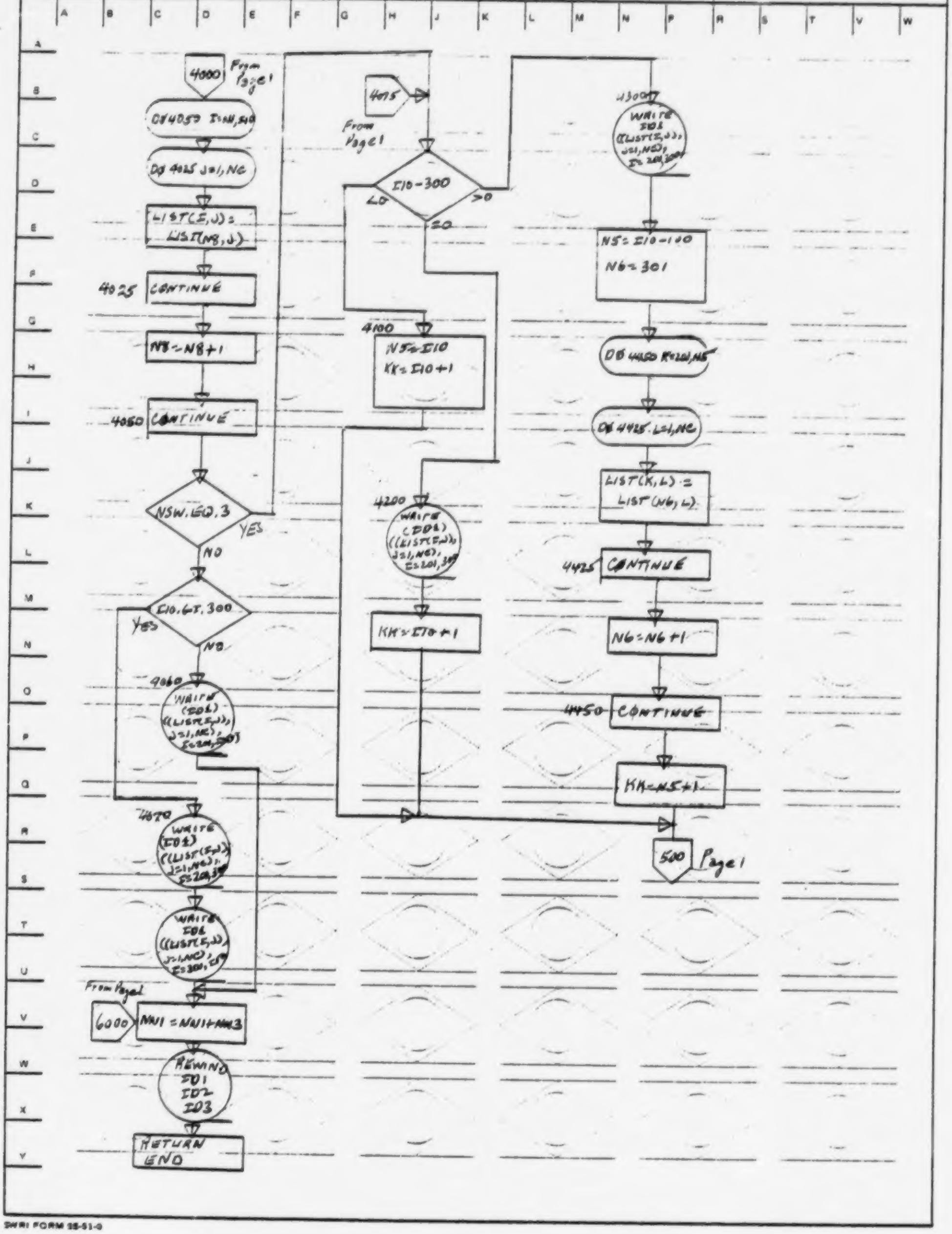
4000
From Page 1
DO 4050 I=NN,510
DO 4025 J=1,NC
LIST(I,J) = LIST(N8,J)
4025 CONTINUE
N8=N8+1
4050 CONTINUE
NSW.EQ.3
YES
NO
I10.GT.300
YES
NO
4060
WRITE (IO1) ((LIST(I,J), J=1,NC), I=201,300)
4070
WRITE (IO2) ((LIST(I,J), J=1,NC), I=201,300)
WRITE IO3 ((LIST(I,J), J=1,NC), I=301, 510)
From Page 1
6000
NN1 = NN1+NN3
REWIND IO1 IO2 IO3
RETURN END
4075
From Page 1
I10-300
<0
>0
=0
4100
N5=I10
KK=I10+1
4200
WRITE (IO2) ((LIST(I,J), J=1,NC), I=201,300)
KK=I10+1
4300
WRITE IO2 ((LIST(I,J), J=1,NC), I=201,300)
N5=I10-100
N6=301
DO 4450 K=201,N5
DO 4425 L=1,NC
LIST(K,L) = LIST(N6,L)
4425 CONTINUE
N6=N6+1
4450 CONTINUE
KK=N5+1
500
Page 1

SWRI FORM 25-51-0

DIAGRAMMING AND CHARTING LAYOUT

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PAGE 1 OF 1 PAGES

APPLICATION WRAP - Subroutine MTBFBE

PROCEDURE

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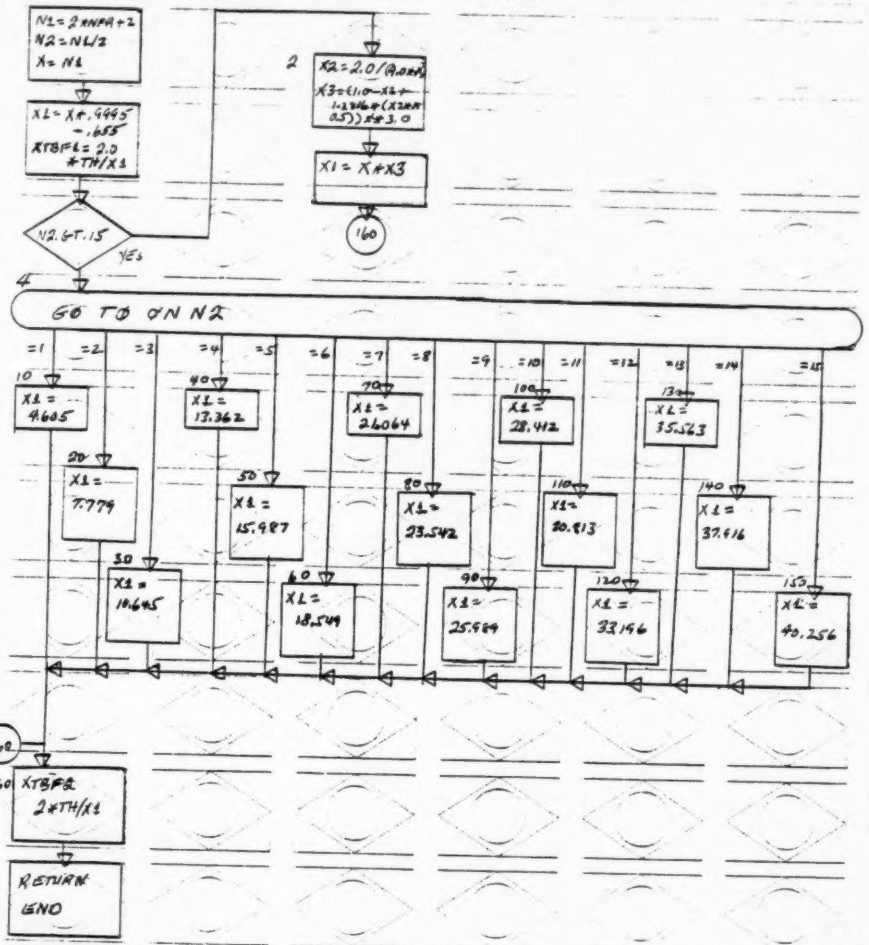
SUBROUTINE MTBFBE (TH, NFR, XTBF1, XTBF2)
COMMON LIST(400,28)


N1 = 2*NFR+2
N2 = N1/2
X = N1
X1 = X*.4445 -.655
XTBF1 = 2.0 *TH/X1
N2.GT.15
YES
2
X2 = 2.0/(9.0*X)
X3 = (1.0-X2+1.2816*(X2**0.5))**3.0
X1 = X*X3
160
4
GO TO ON N2
=1
=2
=3
=4
=5
=6
=7
=8
=9
=10
=11
=12
=13
=14
=15
10 X1 = 4.605
20 X1 = 7.779
30 X1 = 10.645
40 X1 = 13.362
50 X1 = 15.987
60 X1 = 18.549
70 X1 = 21.064
80 X1 = 23.542
90 X1 = 25.989
100 X1 = 28.412
110 X1 = 30.813
120 X1 = 33.196
130 X1 = 35.563
140 X1 = 37.916
150 X1 = 40.256
160
160 XTBF2 = 2*TH/X1
RETURN
END

SWRI FORM 55-51-0

DIAGRAMMING AND CHARTING LAYOUT

DATE 7/8/83

PAGE 1 OF 1 PAGES

APPLICATION WRAP - Subroutine SØRTBE

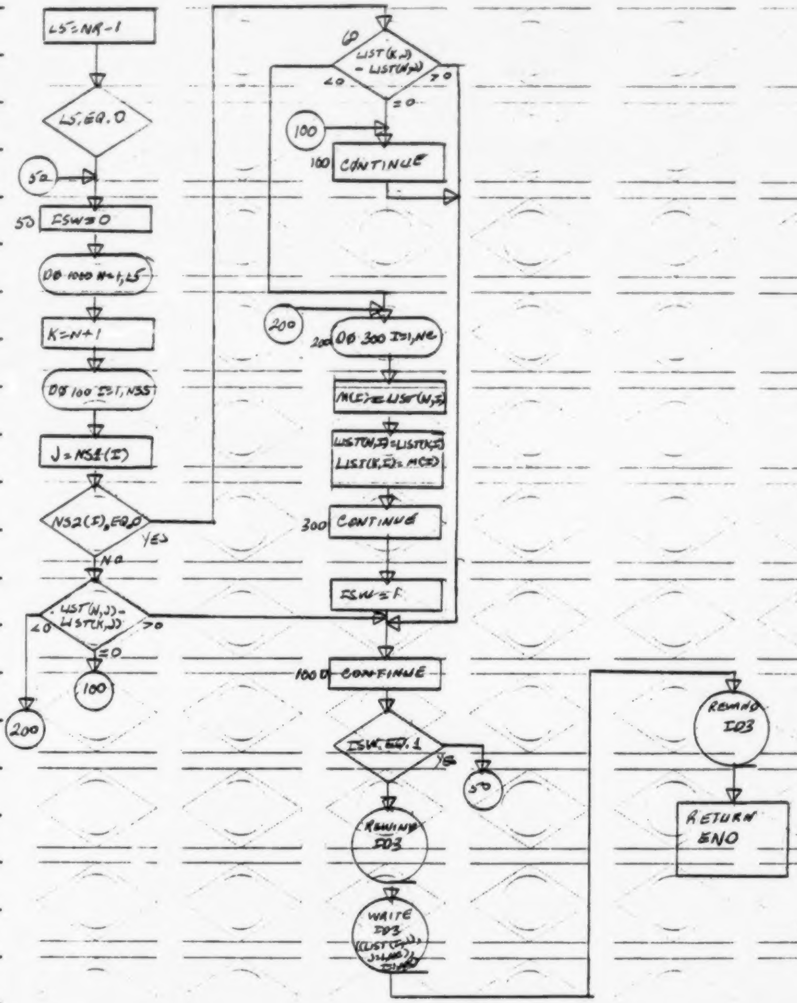
PROCEDURE

DRAWN BY V. Parr

APPROVED

A B C D E F G H J K L M N P R S T V W

```
SUBROUTINE  SØRTBE (IO3,NR,NC,NSS,NS1,NS2)
COMMON LIST(400,28)
DIMENSION NS1(6),NS2(6), M(28)
```



LS=NR-1
LS.EQ.0
50
50 ISW=0
DØ 1000 N=1,LS
K=N+1
DØ 100 I=1,NSS
J=NS1(I)
NS2(I).EQ.0
YES
NO
LIST(N,J)-LIST(K,J)
<0
>0
=0
100
200
60
LIST(K,J)-LIST(N,J)
<0
>0
=0
100
100 CONTINUE
200
200 DØ 300 I=1,NC
M(I)=LIST(N,I)
LIST(N,I)=LIST(K,I)
LIST(K,I)=M(I)
300 CONTINUE
ISW=1
1000 CONTINUE
ISW.EQ.1
YES
50
REWIND IO3
WRITE IO3 ((LIST(I,J), J=1,NR), I=1,NC)
REWIND IO3
RETURN END

SWRI FORM 55-61-0

APPENDIX E-3

WRAP FORTRAN CODE

```
+22222222222222222222222222222222222222222222222222222222222222222222222222222222222

                      $   $  $$$$   $$$$            $    $$$$$  $$$$$     $    $$$
                      $   $  $   $  $   $          $$        $  $        $$   $   $
                      $   $  $   $  $   $         $ $       $   $$$$    $ $       $
                      $   $  $$$$   $$$$            $      $        $  $  $      $$
                      $   $  $   $  $               $     $         $  $$$$$    $
                       $ $   $   $  $               $     $     $   $     $    $
                        $    $$$$   $      $$$$$  $$$$$   $      $$$      $   $$$$$

                                   DEST=VBP+175426003  USER=VBP+175426003  QUEUE=LP
                                       SEQ=9522  QPRI=191  LPP=66  CPL=132  COPIES=

                                                   CREATED:   5-JUN-80   8:23:50
                                                  ENQUEUED:  11-JUL-80   8:14:14
                                                  PRINTING:  11-JUL-80   8:17:16

                                                   PATH=:UDD:VBP+175426003:WRAP

                                                     $   $  $$$$     $    $$$$
                                                     $   $  $   $   $ $   $   $
                                                     $   $  $   $  $   $  $   $
                                                     $ $ $  $$$$   $   $  $$$$
                                                     $ $ $  $ $    $$$$$  $
                                                     $$ $$  $  $   $   $  $
                                                     $   $  $   $  $   $  $

+22222222222222222222222222222222222222222222222222222222222222222222222222222222222


                                                   SOUTHWEST RESEARCH INST, DIV 17

                                                           AOS REV 03.04
                                                         AOS XLPT REV 03.04
```

```
      COMMON LIST(400,28)
      DIMENSION NS1(6),NS2(6),NMK(2),NRL(2),NF(26),NFC(26)
      IN=10
      NOUT=8
      ID1=11
      ID2=12
      ID3=13
      ID4=14
      ID5=15
      IWK=9
      OPEN IN, '@DATA'
      OPEN IWK, 'DATA2'
      OPEN NOUT,'@LIST', ATT='P'
      OPEN ID1, 'ID1'
      OPEN ID2, 'ID2'
      OPEN ID3, 'ID3'
      OPEN ID4, 'ID4'
      OPEN ID5, 'ID5'
      REWIND IWK
      REWIND ID1
      REWIND ID2
      REWIND ID3
      REWIND ID4
      REWIND ID5
      NK2 = 201
      LK=1
      NK1=101
      NC=28
      NMK(1)=0
      NMK(2)=0
   80 READ(IWK,1,END=150) (LIST(1,J),J=1,NC)
    1 FORMAT(I2,I4,3(1X,I2),3X,I2,2I2,I3,11I2,2I3,2(1X,I2),1X,I5,1X,2I2,
     1I4)
      LK=LK+1
      IF(LIST(1,4).GT.5) GO TO 120
   90 DO 100 J=1,NC
      LIST(NK1,J)= LIST(1,J)
  100 CONTINUE
      IF(NK1.EQ.200) GO TO 110
      NK1=NK1+1
      GO TO 80
  110 NMK(1)=NMK(1)+1
      NK1=101
      WRITE(ID4) ((LIST(I,J),J=1,NC),I=101,200)
      GO TO 80
  120 DO 130 J=1,NC
      LIST(NK2,J)=LIST(1,J)
  130 CONTINUE
      IF(NK2.EQ.300) GO TO 140
      NK2=NK2 + 1
      GO TO 80
  140 NMK(2)=NMK(2)+1
      NK2=201
      WRITE(ID5) ((LIST(I,J),J=1,NC),I=201,300)
      GO TO 80
  150 NRL(1)=NK1-101
      NRL(2)=NK2-201
      IF(NRL(1).LE.0) GO TO 155
      NMK(1)= NMK(1)+1
      WRITE(ID4) ((LIST(I,J),J=1,NC),I=101,NK1)
      GO TO 160
  155 NRL(1)=100
  160 IF(NRL(2).LE.0) GO TO 165
```

```
      NMK(2)= NMK(2)+1
      WRITE(ID5)((LIST(I,J),J=1,NC),I=201,NK2)
      GO TO 180
  165 NRL(2)= 100
  180 REWIND IWK
      READ(IN,11) NPC
   11 FORMAT(I5)
      WRITE(NOUT,15) NPC
   15 FORMAT(' NO. OF PROBLEMS IS '2X,I3)
      DO 5000 KPC=1,NPC
      READ(IN,21) NWWS,NWAP,NSRT,NSS,(NS1(I),I=1,6),(NS2(I),I=1,6),NPRT
   21 FORMAT(17I4)
      WRITE(NOUT,13) NWWS,NWAP,NSRT,NSS,(NS1(I),I=1,6),(NS2(I),I=1,6),
     1NPRT
   13 FORMAT('1 NWWS='1X,I2'NWAP='I2'NSRT='I2'NSS='I2'NS1='6I2'NS2='6I2
     1'NPRT='I2  )
      REWIND ID4
      REWIND ID5
  190 IF(NWWS.EQ.2) GO TO 260
      IF(NWAP.EQ.1) GO TO 230
  195 GO TO (200,210,290),NSRT
  200 NS1(1)= 5
      NS1(2)= 6
      NS1(3)= 7
      NS1(4)= 8
      NS1(5)= 2
      NSS = 6
      NS1(6) = 1
      GO TO 290
  210 NS1(1)= 5
      NS1(2)= 6
      NS1(3)= 7
      NS1(4)= 9
      NSS=4
      GO TO 290
  230 GO TO (240,250,290) ,NSRT
  240 NS1(1)=1
      NS1(2)=5
      NS1(3)=6
      NS1(4)=7
      NS1(5)=8
      NS1(6)=2
      NSS=6
      GO TO 290
  250 NS1(1) = 1
      NS1(2) = 5
      NS1(3) = 6
      NS1(4) = 7
      NS1(5) = 9
      NSS = 5
      GO TO 290
  260 IF(NWAP.EQ.1) GO TO 280
      IF(NSRT.EQ.1) GO TO 270
      GO TO 285
  270 NS1(1)=4
      NS1(2)=2
      NS1(3)=1
      NSS=3
      GO TO 285
  280 IF(NSRT.NE.1) GO TO 285
      NS1(1)=1
      NS1(2)=4
      NS1(3)=2
      NSS=3
  285 IS=NMK(2)
      ID8=ID5
      NLS=NRL(2)
      GO TO 300
  290 IS=NMK(1)
      ID8=ID4
      NLS=NRL(1)
  300 DO 400 I2=1,IS
      IF(I2.EQ.IS) GO TO 305
      NXR=100
      GO TO 310
  305 NXR=NLS
  310 READ(ID8) ((LIST(I,J),J=1,NC),I=1,NXR)
      CALL SORTBE(ID3,NXR,NC,NSS,NS1,NS2)
      NN3=NXR
      IF(I2.EQ.1) GO TO 320
      CALL MERGBE(ID1,ID2,ID3,NN3,NN2,NN1,NC,NSS,NS1,NS2)
      NN2=NN1
      KSAV=ID1
      ID1=ID3
      ID3 = ID2
      ID2=KSAV
      GO TO 400
  320 KSAV = ID3
      ID3=ID2
      ID2=KSAV
      NN2=NXR
  400 CONTINUE
      IF(NSRT.GT.2) GO TO 410
      IF(NPRT .GT.0) GO TO 410
      GO TO 440
  410 WRITE(NOUT,61) (NS1(I),I=1,NSS)
   61 FORMAT( '1  SORT ORDER IS' 6I3 )
      DO 430 I2=1,IS
      IF(I2.EQ.IS) GO TO 415
      NXR=100
      GO TO 420
  415 NXR=NLS
  420 READ(ID2) ((LIST(I,J),J=1,NC),I=1,NXR)
      WRITE(NOUT,71) ((LIST(I,J),J=1,NC),I=1,NXR)
  430 CONTINUE
   71 FORMAT(1X,I2,I6,6I4,I5,11I4,2I5,2I4,I7,3I4
      REWIND ID2
      IF(NSRT.GT.2) GO TO 5000
  440 IF(NWWS.EQ.2) GO TO 460
      IF(NWAP.EQ.2) GO TO 460
      IF(NSRT.EQ.2) GO TO 450
      ISW3=1
      ISW1=0
      NSW3=1
      WRITE(NOUT,441)
  441 FORMAT('1 WASTEWATER TREATMENT PLANT REPORT-RELIABILITY STATISTICS
     1 BY GENERIC GROUP/APPLICATION SIZE RANGE BY PLANT'  //)
      GO TO 540
  450 NSW3=3
      ISW1=0
      ISW3=3
      WRITE(NOUT,451)
  451 FORMAT('1 WASTEWATER TREATMENT PLANT REPORT-NUMBER OF FAILURES BY
     1SUBCOMPONENT BY SIZE RANGE FOR EACH PLANT' //)
      GO TO 540
  460 IF(NSRT.EQ.2) GO TO 470
```

```
      ISW1=1
      NSW3=2
      ISW3=1
      WRITE(NOUT,461)
  461 FORMAT('1 WASTEWATER TREATMENT PLANT REPORT-RELIABILITY STATISTICS
     1 BY GENERIC GROUP/APPLICATION AND SIZE RANGE' //)
      GO TO 540
  470 ISW1=1
      NSW3=4
      ISW3=3
      WRITE(NOUT,471)
  471 FORMAT('1   WWTP REPORT-FAILURES BY SUBCOMPONENT BY SIZE RANGE'//)
      GO TO 540
  480 IF(NWAP.NE.1) GO TO 490
      ISW1=0
      NSW3=5
      ISW3=1
      WRITE(NOUT,481)
  481 FORMAT('1 WWTP REPORT-RELIABILITY OF SLUDGE PROCESSES BY PLANT'//)
      GO TO 540
  490 ISW1=1
      NSW3=6
      ISW3=1
      WRITE(NOUT,491)
  491 FORMAT('1 WWTP REPORT-RELIABILITY OF SLUDGE PROCESSES' //)
       WRITE(NOUT,883)
  540 NSW1=0
      NSW2=0
      ISWT=0
      N1=1
      NSGN=-1
      DO 3000 I2=1,I5
      IF(I2.EQ.I5) GO TO 545
      NXR= 100
      GO TO 550
  545 NXR=NLS
  550 IF(NSGN.GT.0) GO TO 555
      N4=NXR
      N3=1
      GO TO 560
  555 N4=NXR + 100
      N3 = 101
  560 N2= N3
      READ(ID2) ((LIST(I,J),J=1,NC),I=N3,N4)
  570 N11=LIST(N1,1)
      N21=LIST(N1,2)
      N41=LIST(N1,4)
      N51=LIST(N1,5)
      N61=LIST(N1,6)
      N71=LIST(N1,7)
      N81=LIST(N1,8)
      N91=LIST(N1,9)
      IF(NSW1.GT.0) GO TO 1000
      NZ = N81 + 1
      KK=N1
      NFR=0
      TH=0.0
      TY=0.0
      CM=0.0
      NFP=0
      THD=0.0
      PM=0.0
      NU=0
      DT=0.0
      ACH=0.0
      GO TO (600,600,680,680,880,880) ,NSW3
  600 IF(ISW3.EQ.0) GO TO 1030
      CALL WRTSHE(N11,NS1,N61,NOUT,ISW1,N71)
      WRITE(NOUT,681)
  681 FORMAT(3X,' SIZE- CAPACITY'14X,'NO.'7X,'OPER.'4X,'NO.'3X,'PM-HRS/'
     14X,'CM-HRS/'          )
      WRITE (NOUT,682)
  682 FORMAT(31X,'UNITS' 7X,'HRS.' 3X, 'FAIL.' 1X, 'UNIT/YEAR' 2X, 'UNIT'
     1/YEAR' 5X,'MTTR' 7X,'MTBF'6X,'90% CL'6X,'AVI'8X,'AVO'  /)
      GTH=0.0
      NTF=0
      GPM=0.0
      GCM=0.0
      GYR=0.0
      NNU=0
      GACH=0.0
      GTHD=0.0
      GO TO 1030
  680 IF(ISW3.NE.3) GO TO 695
      CALL WRTSBE(N11,N51,N61,NOUT,ISW1,N71)
      WRITE(NOUT,683)
  683 FORMAT(1X,'SUB.COMP.    SIZE    RANGE    CODES' /)
      WRITE(NOUT,687)
  687 FORMAT(3X'CODES      00  01  02  03  04  05  06  07  08  09  10  11
     1  12  13  14  15  16  17  18  19  20  21  22  23  24  25      TOTAL
     2S' /)
      NTF = 0
      ISW3 = 2
      DO 685 K=1,26
  685 NFC(K)=0
  695 NRF=0
      DO 700 K=1,26
  700 NF(K)=0
      GO TO 1030
  880 IF(ISW1.EQ.1 ) GO TO 1030
      IF(ISW3.EQ.0 ) GO TO 1030
      WRITE(NOUT,881) N11
  881 FORMAT(// ' PLANT NUMBER IS' I4, / )
      ISW3=0
  885 WRITE(NOUT,883)
  883 FORMAT(10X,'PROCESS'  39X, 'OP. HOURS' 3X, 'NO. FAIL' 5X,
     1'MTBF' 8X, '90% CL',7X,'AVAIL'  /)
      GO TO 1030
 1000 N12=LIST(N2,1)
      N22=LIST(N2,2)
      N42=LIST(N2,4)
      N52=LIST(N2,5)
      N62=LIST(N2,6)
      N72=LIST(N2,7)
      N82=LIST(N2,8)
      N92=LIST(N2,9)
      KK=N2
      NZ = N82 + 1
      GO TO (1010,1010,1010,1010,1020,1020) ,NSW3
 1010 IF(N72.NE.N71) GO TO 1250
      IF(N62.NE.N61) GO TO 1250
      IF(N52.NE.N51) GO TO 1250
      IF (NSW3.GT.2) GO TO 1015
      IF(N82.NE.N81) GO TO 1250
      GO TO 1030
 1015 IF(N92.NE.N91) GO TO 1250
```

```
      GO TO 1030
 1020 IF(N42.NE.N41) GO TO 1250
 1030 IF(LIST(KK,14).EQ.99) GO TO 1040
      NNF = LIST(KK,14)
      GO TO 1042
 1040 NNF=0
 1042 IF(LIST(KK,24).EQ.1) GO TO 1050
      NFR = NFR + NNF
      GO TO 1050
 1065 IF(LIST(KK,24).EQ.2) GO TO 1045
      NSW4=0
      CALL ACHMBE(KK,ACH,NSW4,CM,PM,THD)
      GO TO 1160
 1045 NSW4 = 1
 1047 CALL ACHMBE(KK,ACH,NSW4,CM,PM,THD)
      GO TO 1160
 1050 DT = DT + LIST(KK,25)
      GO TO (1055,1055,1080,1080,1055,1055) ,NSW3
 1055 IF(NSW1.EQ.0) GO TO 1060
      IF(N21.EQ.N22) GO TO 1062
      GO TO 1060
 1060 XY= LIST(KK,27)- LIST(KK,12)
      XM= LIST(KK,26)- LIST(KK,11)
      XP= LIST(KK,13)
      Y= (XY +(XM/12.0))* XP/100.0
      H= Y*8760.0
      TY= TY+Y
      TH= TH+H
      NU= NU+1
      GO TO 1065
 1062 IF(N11.EQ.N12) GO TO 1065
      GO TO 1060
 1080 IF(NZ.GT.26) NZ=1
      NF(NZ) = NF(NZ) + NNF
      NFC(NZ) = NFC(NZ) + NNF
      NTF = NTF + NNF
 1160 N2= N2+1
      N1 = N2 - 1
      IF(N2.GT.N4) GO TO 1190
      IF(NSW1.GT.0) GO TO 570
      NSW1 = 1
      GO TO 570
 1190 NSGN=-NSGN
      NSW1=1
      IF(I5.EQ.I2) GO TO 1200
      GO TO 3000
 1200 NSW2 = 1
      IF(NSW3.GT.2) GO TO 1250
      ISW3 = 1
 1250 GO TO (1260,1260,1290,1290,1260,1260) ,NSW3
 1260 CALL MTBFBE(TH,NFR,XTBF1,XTBF2)
      IF(NSW3.GT.3) GO TO 1270
      CALL MANTBE(PM,CM,PMY,CMY,TY,XMTTR,NFR,NU,ACH)
      AVI= 1.0/ (1.0 + (XMTTR/XTBF1))
      AVO= (TH-THD)/TH
      CALL WRTBBE(N81,NU,TH,NFR,PMY,CMY,XMTTR,XTBF1,XTBF2,NOUT,
     1AVI,AVO)
      GO TO 1280
 1270 AV=(TH-DT)/TH
      CALL WRTRBE(N41,TH,NFR,XTBF1,XTBF2,AV,NOUT)
 1280 GO TO (1300,1300,1400,1400,1500,1500) ,NSW3
 1290 DO 1295 J=1,26
 1295 NRF = NRF + NF(J)
```

```
      GO TO 1280
 1300 IF(NSW2.EQ.0) GO TO 1310
      IF(ISW3.EQ.1) GO TO 1320
      GO TO 3000
 1310 IF(N52.NE.N51) GO TO 1320
      IF(N62.NE.N61) GO TO 1320
      IF(N72.NE.N71) GO TO 1320
      GO TO 1340
 1320 ISW3=1
      GTH=GTH + TH
      NTF= NTF + NFR
      GPM= GPM + PM
      GCM= GCM + CM
      GACH = GACH +ACH
      GYR= GYR + TY
      GTHD=GTHD+THD
      NNU = NNU +NU
      CALL MTBFBE(GTH,NTF,XTBF1,XTBF2)
      CALL MANTBE(GPM,GCM,PMY,CMY,GYR,XMTTR,NTF,NNU,GACH)
      AVI=1.0/(1.0+(XMTTR/XTBF1))
      AVO=(GTH-GTHD)/GTH
      WRITE(NOUT,1311) NNU,GTH,NTF,PMY,CMY,XMTTR,XTBF1,XTBF2,AVI,AVO
 1311 FORMAT(1X,'OVERALL STATISTICS'12X,I5,2X,E9.4,2X,I5,7(2X,E9.4)
     1///)
      IF(NSW2.EQ.0) GO TO 1350
      GO TO 3000
 1340 ISW3=0
      GTH=GTH+TH
      NTF=NTF + NFR
      GPM=GPM + PM
      GCM=GCM + CM
      GYR=GYR + TY
      NNU=NNU + NU
      GACH=GACH + ACH
      GTHD= GTHD+THD
 1350 N1=N2
      NSW1 =0
      GO TO 570
 1400 IF(NSW2.EQ.1) GO TO 1450
      IF(N52.NE.N51) GO TO 1445
      IF(N62.NE.N61) GO TO 1445
      IF(N72.NE.N71) GO TO 1445
 1440 ISW3=2
      WRITE(NOUT,982) N91,(NF(I),I=1,26),NRF
      GO TO 1350
 1445 ISW3 = 3
      WRITE(NOUT,982) N91,(NF(I),I=1,26),NRF
      WRITE(NOUT,983)(NFC(I),I=1,26),NTF
      GO TO 1350
 1450 WRITE(NOUT,982) N91,(NF(I),I=1,26),NRF
      WRITE(NOUT,983) (NFC(I),I=1,26),NTF
  982 FORMAT(4X,I3, 4X,26(1X,I3),6X,I6 /)
  983 FORMAT(1X'TOTALS'  4X,26(1XI3),6X,I6  ///  )
      GO TO 3000
 1500 IF(NSW2.EQ.1) GO TO 3000
      IF(ISW1.EQ.1) GO TO 1350
      IF(N11.EQ.N12) GO TO 1510
      ISW3 =1
      GO TO 1350
 1510 ISW3 =0
      GO TO 1350
 3000 CONTINUE
 5000 CONTINUE
```

```
STOP
END
```

```
+3333333333333333333333333333333333333333333333333333333333333333333333333333333333

                      $   $  $$$$   $$$$            $    $$$$$  $$$$$     $    $$$
                      $   $  $   $  $   $          $$        $  $        $$   $   $
                      $   $  $   $  $   $         $ $       $   $$$$    $ $       $
                      $   $  $$$$   $$$$            $      $        $  $  $     $$
                      $   $  $   $  $               $     $         $  $$$$$   $
                       $ $   $   $  $               $     $     $   $     $   $
                        $    $$$$   $      $$$$$  $$$$$   $      $$$      $   $$$$$

                                   DEST=VBP+175426003  USER=VBP+175426003  QUEUE=LP
                                       SEQ=9523  QPRI=191  LPP=66  CPL=132  COPIES=

                                                    CREATED:  30-SEP-79  13:31:50
                                                   ENQUEUED:  11-JUL-80   8:14:14
                                                   PRINTING:  11-JUL-80   8:18:05

                                                   PATH=:UDD:VBP+175426003:ACHMBE

                                                  $     $$$   $   $  $   $  $$$$   $$
                                                 $ $   $   $  $   $  $$ $$  $   $  $
                                                $   $  $      $   $  $ $ $  $   $  $
                                                $   $  $      $$$$$  $ $ $  $$$$   $$
                                                $$$$$  $      $   $  $   $  $   $  $
                                                $   $  $   $  $   $  $   $  $   $  $
                                                $   $   $$$   $   $  $   $  $$$$   $$

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                                                   SOUTHWEST RESEARCH INST. DIV 17

                                                            AOS REV 03.04
                                                         AOS XLPT REV 03.04
```

```
      SUBROUTINE ACHMBE(KK,ACH,NSW4,CM,PM,THD)
      COMMON LIST(400,28)
      K1=LIST(KK,17)
      IF(K1.LE.0) GO TO 10
      IF(K1.GT.7) GO TO 80
      GO TO 15
   10 HM=0.0
      GO TO 90
   15 GO TO (20,30,40,50,60,70,80) ,K1
   20 HM=1.0
      GO TO 90
   30 HM=3.0
      GO TO 90
   40 HM=15.0
      GO TO 90
   50 HM=96.0
      GO TO 90
   60 HM=444.0
      GO TO 90
   70 HM=2520.0
      GO TO 90
   80 HM=4320.0
   90 N8= LIST(KK,14)
       IF(N8.LE.0) N8=1
       IF(N8.EQ.99) N8 = 1
       K1 = LIST(KK,18)
       IF(K1.LE.0) GO TO 81
       GO TO 82
   81  CM1 = 0.5
       GO TO 88
   82  GO TO (83,84,85,86) , K1
   83  CM1 = 1.0
       GO TO 88
   84  CM1 = 3.0
       GO TO 88
   85  CM1 = 15.0
       GO TO 88
   86  CM1 = 96.0
   88  THD= THD + HM
       CM1 = CM1*N8
       IF(NSW4.EQ.0) GO TO 95
       CM = CM1    + CM
       CH=LIST(KK,28)
       ACH = ACH + CH
       IF(HM.GT.CH) GO TO 100
       THD=THD+CH-HM
       GO TO 100
   95  PM = PM + CM1
  100  CONTINUE
      RETURN
      END
```

```
+444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444

                          $   $  $$$$   $$$$               $    $$$$$  $$$$$     $    $$$
                          $   $  $   $  $   $             $$        $  $        $$   $   $
                          $   $  $   $  $   $            $ $       $   $$$$    $ $       $
                          $   $  $$$$   $$$$               $      $        $  $  $      $$
                          $   $  $   $  $                  $     $         $  $$$$$    $
                           $ $   $   $  $                  $     $     $   $     $    $
                            $    $$$$   $        $$$$$  $$$$$    $      $$$      $    $$$$$

                                      DEST=VBP+175426003  USER=VBP+175426003  QUEUE=LP
                                           SEG=9524  QPRI=191  LPP=66  CPL=132  COPIES=

                                                     CREATED:  15-SEP-79  15:28:42
                                                    ENQUEUED:  11-JUL-80   8:14:14
                                                    PRINTING:  11-JUL-80   8:18:16

                                                    PATH=:UDD:VBP+175426003:MANTBE

                                              $   $    $    $   $  $$$$$  $$$$   $$
                                              $$ $$   $ $   $$  $    $    $   $  $
                                              $ $ $  $   $  $ $ $    $    $   $  $
                                              $ $ $  $   $  $  $$    $    $$$$   $$
                                              $   $  $$$$$  $   $    $    $   $  $
                                              $   $  $   $  $   $    $    $   $  $
                                              $   $  $   $  $   $    $    $$$$   $$

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                                                   SOUTHWEST RESEARCH INST. DIV 17

                                                            AOS REV 03.04
                                                       AOS XLPT REV 03.04
```

```
      SUBROUTINE MANTBE(PM,CM,PMY,CMY,TY,XMTTR,NFR,NU,ACH)
      COMMON LIST(400,28)
      IF(NU.LE.0) GO TO 10
      XNU=NU
      GO TO 20
   10 XNU=1.0
   20 IF(TY.LE.0.)GO TO 30
      XTY=TY
      GO TO 60
   30 XTY=1.0
   60 IF(NFR.LE.0) GO TO 70
      XNFR=NFR
      GO TO 80
   70 XNFR=1.0
   80 PMY= PM/(XNU*XTY)
      CMY= CM/(XNU*XTY)
      XMTTR= ACH/XNFR
      RETURN
      END
```

```
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                      $   $  $$$$   $$$$            $    $$$$$  $$$$$     $    $$$
                      $   $  $   $  $   $          $$        $  $        $$   $   $
                      $   $  $   $  $   $         $ $       $   $$$$    $ $       $
                      $   $  $$$$   $$$$            $      $        $  $  $     $$
                      $   $  $   $  $               $     $         $  $$$$$   $
                       $ $   $   $  $               $     $     $   $     $   $
                        $    $$$$   $      $$$$$  $$$$$   $      $$$      $   $$$$$

                                   DEST=VBP+175426003  USER=VBP+175426003  QUEUE=LP
                                       SEQ=9525  QPRI=191  LPP=66  CPL=132  COPIES=

                                                   CREATED:  15-SEP-79  15:51:46
                                                  ENQUEUED:  11-JUL-80   8:14:14
                                                  PRINTING:  11-JUL-80   8:18:24

                                                  PATH=:UDD:VBP+175426003:MERGBE

                                             $   $  $$$$$  $$$$    $$$$  $$$$   $$
                                             $$ $$  $      $   $  $      $   $  $
                                             $ $ $  $      $   $  $      $   $  $
                                             $ $ $  $$$$   $$$$   $      $$$$   $$
                                             $   $  $      $ $    $  $$  $   $  $
                                             $   $  $      $  $   $   $  $   $  $
                                             $   $  $$$$$  $   $   $$$$  $$$$   $$
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                                                  SOUTHWEST RESEARCH INST. DIV 17

                                                           AOS REV 03.04
                                                        AOS XLPT REV 03.04
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```
      SUBROUTINE MERGHE(ID1,ID2,ID3,NN3,NN2,NN1,NC,NSS,NS1,NS2)
      COMMON LIST(400,28)
      DIMENSION  NS1(6),NS2(6)
      NOUT = 8
      KK=1
      N5=0
      N4=NN3+100
      N3=101
      NSW=0
      I4=1
      I2=NN2/100
      N22=I2*100
      N1=200
      IF(N22.EQ.NN2) GO TO 100
      N22=NN2-N22
      I2=I2+1
      GO TO 200
  100 N22=0
  200 READ(ID3) ((LIST(I,J),J=1,NC),I=N3,N4)
  500 IF(I4-I2) 550,600,700
  550 I8=100+N5
      GO TO 800
  600 IF(N22.EQ.0) GO TO 550
      I8=N22+N5
      GO TO 800
  700 IF(NSW.EQ.3) GO TO 725
      I10=N1+NN3-N3+101
      N8=N3
      NSW=2
      N1=N1+1
      GO TO 4000
  725 IF(N5.EQ.200) GO TO 6000
      WRITE(ID1) ((LIST(I,J),J=1,NC),I=201,N5)
      GO TO 6000
  800 READ(ID2)             ((LIST(I,J),J=1,NC),I=KK,I8)
  801  CONTINUE
      I4=I4+1
      N2=1
      IF(NSW.EQ.0) GO TO 2000
      I10=I8
      GO TO 4075
 2000 DO 2100 K=1,NSS
      J=NS1(K)
      IF(NS2(K).EQ.0) GO TO 2050
      IF(LIST(N2,J)-LIST(N3,J)) 2300,2100,2200
 2050 IF(LIST(N3,J)-LIST(N2,J)) 2300,2100,2200
 2100 CONTINUE
      GO TO 2300
 2200 N=N2
      N2=N2+1
      N6=2
      GO TO 2400
 2300 N6=3
      N=N3
      N3=N3+1
 2400 N1=N1+1
      IF(N1.LT.301)  GO TO 2500
      WRITE(ID1) ((LIST(I,J),J=1,NC),I=201,300)
      N1=201
 2500 DO 2600 K=1,NC
      LIST(N1,K)= LIST(N,K)
 2600 CONTINUE
      IF(N6.EQ.2) GO TO 2700
      IF(N3.GT.N4) GO TO 3000
      GO TO 2000
 2700 IF(N2.GT.I8) GO TO 500
      GO TO 2000
 3000 I10=N1+I8-N2+1
      NSW=3
      N8=N2
      N1=N1+1
 4000 DO 4050 I=N1,I10
      DO 4025 J=1,NC
      LIST(1,J)=LIST(N8,J)
 4025 CONTINUE
      N8=N8+1
 4050 CONTINUE
      IF(NSW.EQ.3) GO TO 4075
      IF(I10.GT.300) GO TO 4070
 4060 WRITE(ID1) ((LIST(I,J),J=1,NC),I=201,I10)
      GO TO 6000
 4070 WRITE(ID1) ((LIST(I,J),J=1,NC),I=201,300)
      WRITE(ID1) ((LIST(I,J),J=1,NC),I=301,I10)
      GO TO 6000
 4075 IF(I10-300) 4100,4200,4300
 4100 N5=I10
      KK=I10+1
      GO TO 500
 4200 WRITE(ID1) ((LIST(I,J),J=1,NC),I=201,300)
      KK=201
      N5=200
      GO TO 500
 4300 WRITE(ID1) ((LIST(I,J),J=1,NC),I=201,300)
      N5=I10-100
      N6=301
      DO 4450 K=201,N5
      DO 4425 L=1,NC
      LIST(K,L)= LIST(N6,L)
 4425 CONTINUE
      N6=N6+1
 4450 CONTINUE
      KK=N5+1
      GO TO 500
 6000 NN1=NN2+ NN3
      REWIND ID1
      REWIND ID2
      REWIND ID3
      RETURN
      END
```

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                      $   $  $$$$   $$$$            $    $$$$$  $$$$$     $    $$$
                      $   $  $   $  $   $          $$        $  $        $$   $   $
                      $   $  $   $  $   $         $ $       $   $$$$    $ $       $
                      $   $  $$$$   $$$$            $      $        $  $  $     $$
                      $   $  $   $  $               $     $         $  $$$$$   $
                       $ $   $   $  $               $     $     $   $     $   $
                        $    $$$$   $      $$$$$  $$$$$   $      $$$      $   $$$$$

                                   DEST=VBP+175426003  USER=VBP+175426003  QUEUE=LP
                                       SEQ=9526  QPRI=191  LPP=66  CPL=132  COPIES=

                                                    CREATED:  15-SEP-79  15:54:48
                                                   ENQUEUED:  11-JUL-80   8:14:16
                                                   PRINTING:  11-JUL-80   8:18:41

                                                   PATH=:UDD:VBP+175426003:MTBFBE

                                              $   $  $$$$$  $$$$   $$$$$  $$$$   $$
                                              $$ $$    $    $   $  $      $   $  $
                                              $ $ $    $    $   $  $      $   $  $
                                              $ $ $    $    $$$$   $$$$   $$$$   $$
                                              $   $    $    $   $  $      $   $  $
                                              $   $    $    $   $  $      $   $  $
                                              $   $    $    $$$$   $      $$$$   $$
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                                                  SOUTHWEST RESEARCH INST. DIV 17

                                                           AOS REV 03.04
                                                        AOS XLPT REV 03.04
```

```
      SUBROUTINE MTBFBE(TH,NFR,XTBF1,XTBF2)
      COMMON LIST(400,28)
      N1=2*NFR+2
      N2=N1/2
      X=N1
      X1=X*.9995-.655
      XTBF1=2.0*TH/X1
      IF(N2.GT.15) GO TO 2
      GO TO 4
    2 X2=2.0/(9.0*X)
      X3=(1.0-X2+1.2816*(X2**0.5))**3.0
      X1=X*X3
      GO TO 160
    4 GO TO (10,20,30,40,50,60,70,80,90,100,110,120,130,140,150) ,N2
   10 X1=4.605
      GO TO 160
   20 X1=7.779
      GO TO 160
   30 X1=10.645
      GO TO 160
   40 X1=13.362
      GO TO 160
   50 X1=15.987
      GO TO 160
   60 X1=18.549
      GO TO 160
   70 X1=21.064
      GO TO 160
   80 X1=23.542
      GO TO 160
   90 X1=25.989
      GO TO 160
  100 X1=28.412
      GO TO 160
  110 X1=30.813
      GO TO 160
  120 X1=33.196
      GO TO 160
  130 X1=35.563
      GO TO 160
  140 X1=37.916
      GO TO 160
  150 X1=40.256
  160 XTBF2 = 2*TH/X1
      RETURN
      END
```

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                       $   $  $$$$   $$$$            $    $$$$$  $$$$$     $    $$$
                       $   $  $   $  $   $          $$        $  $        $$   $   $
                       $   $  $   $  $   $         $ $       $   $$$$    $ $       $
                       $   $  $$$$   $$$$            $      $        $  $  $      $$
                       $   $  $   $  $               $     $         $  $$$$$    $
                        $ $   $   $  $               $     $     $   $     $    $
                         $    $$$$   $      $$$$$  $$$$$   $      $$$      $   $$$$$

                                   DEST=VBP←175426003  USER=VBP←175426003  QUEUE=LP
                                        SEQ=9527  QPRI=191  LPP=66  CPL=132  COPIES=

                                                     CREATED:  15-SEP-79  15:57:34
                                                    ENQUEUED:  11-JUL-80   8:14:16
                                                    PRINTING:  11-JUL-80   8:18:51

                                                    PATH=:UDD:VBP←175426003:SORTBE

                                                 $$$    $$$   $$$$   $$$$$  $$$$   $$
                                                $   $  $   $  $   $    $    $   $  $
                                                $      $   $  $   $    $    $   $  $
                                                 $$$   $   $  $$$$     $    $$$$   $$
                                                    $  $   $  $ $      $    $   $  $
                                                $   $  $   $  $  $     $    $   $  $
                                                 $$$    $$$   $   $    $    $$$$   $$

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                                                     SOUTHWEST RESEARCH INST. DIV 17


                                                              AOS REV 03.04
                                                           AOS XLPT REV 03.04
```

```
      SUBROUTINE SUPTRE(ID3,NR,NC,NSS,NS1,NS2)
      COMMON  LIST(400,28)
      DIMENSION  NS1(6),NS2(6),M(28)
      L5=NR-1
      IF(L5.EQ.0) GO TO 2000
   50 ISW=0
      DO 1000 N=1,L5
      K=N+1
      DO 100 I=1,NSS
      J=NS1(I)
      IF(NS2(I).EQ.0) GO TO 60
      IF(LIST(N,J)-LIST(K,J)) 200,100,1000
   60 IF(LIST(K,J)-LIST(N,J)) 200,100,1000
  100 CONTINUE
      GO TO 1000
  200 DO 300 I=1,NC
      M(I)= LIST(N,I)
      LIST(N,I)= LIST(K,I)
      LIST(K,I)= M(I)
  300 CONTINUE
      ISW=1
 1000 CONTINUE
      IF(ISW.EQ.1) GO TO 50
 2000 REWIND ID3
      WRITE(ID3) ((LIST(I,J),J=1,NC),I=1,NR)
      REWIND ID3
      RETURN
      END
```

```
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                    $   $  $$$$   $$$$            $    $$$$$  $$$$$     $    $$$
                    $   $  $   $  $   $          $$        $  $        $$   $   $
                    $   $  $   $  $   $          $ $       $   $$$$    $ $       $
                    $   $  $$$$   $$$$            $      $        $  $  $     $$
                    $   $  $   $  $               $     $         $  $$$$$   $
                     $ $   $   $  $               $     $     $   $     $   $
                      $    $$$$   $      $$$$$  $$$$$   $      $$$      $   $$$$$

                                 DEST=VBP+175426003  USER=VBP+175426003  QUEUE=LP
                                     SEQ=9528  QPRI=191  LPP=66  CPL=132  COPIES=

                                                  CREATED:  31-OCT-79   8:27:12
                                                 ENQUEUED:  11-JUL-80   8:14:16
                                                 PRINTING:  11-JUL-80   8:19:00

                                                 PATH=:UDD:VBP+175426003:WRTRBE

                                            $   $  $$$$   $$$$$  $$$$   $$$$   $$
                                            $   $  $   $    $    $   $  $   $  $
                                            $   $  $   $    $    $   $  $   $  $
                                            $ $ $  $$$$     $    $$$$   $$$$   $$
                                            $ $ $  $ $      $    $ $    $   $  $
                                            $$ $$  $  $     $    $  $   $   $  $
                                            $   $  $   $    $    $   $  $$$$   $$

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                                                 SOUTHWEST RESEARCH INST. DIV 17


                                                          AOS REV 03.04
                                                       AOS XLPT REV 03.04
```

```
      SUBROUTINE WRTRBE(N41,TH,NFR,XTBF1,XTBF2,AV,NOUT)
      COMMON LIST(400,28)
      IF(N41.GT.17) GO TO 10
      K1=N41-5
      GO TO 20
   10 WRITE(NOUT,580)
  580 FORMAT(' UNDEFINED'  44X,Z  )
      GO TO 150
   20  GO TO (30,40,50,60,70,80,90,100,120,130,140,145),K1
   30 WRITE(NOUT,581)
  581 FORMAT(' SLUDGE PROCESS EXTERNAL TO WW TREAT. PROCESS' 9X,Z  )
      GO TO 150
   40 WRITE(NOUT,582)
  582 FORMAT(' ANAEROBIC DIGESTION' 34X, Z )
      GO TO 150
   50 WRITE(NOUT,583)
  583 FORMAT(' AEROBIC DIGESTION' 36X , Z )
      GO TO 150
   60 WRITE(NOUT,584)
  584 FORMAT(' HEAT TREATMENT' 39X, Z )
      GO TO 150
   70 WRITE(NOUT,585)
  585 FORMAT(' INCINERATION' 41X, Z )
      GO TO 150
   80 WRITE(NOUT,586)
  586 FORMAT( ' SLUDGE THICKENING GRAVITY' 28X, Z )
      GO TO 150
   90 WRITE(NOUT,587)
  587 FORMAT( ' SLUDGE THICKENING DAF' 32X, Z  )
      GO TO 150
  100 WRITE(NOUT,588)
  588 FORMAT( ' CENTRIFUGE,SOLID BOWL' 32X, Z  )
      GO TO 150
  120 WRITE(NOUT,589)
  589 FORMAT( ' CENTRIFUGE BASKET' 36X, Z )
      GO TO 150
  130 WRITE(NOUT,590)
  590 FORMAT( ' CENTRIFUGE,NOZZLE' 36X, Z )
      GO TO 150
  140 WRITE(NOUT,591)
  591 FORMAT( ' VACUUM FILTER' 40X, Z )
      GO TO 150
  145 WRITE(NOUT,596)
  596 FORMAT( ' BELT PRESS' 43X,  Z )
  150 WRITE(NOUT,595) TH,NFR,XTBF1,XTBF2,AV
  595 FORMAT('+' E10.3,3X,I7,3(3X,E10.3)     )
      RETURN
      END
```

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                     $   $  $$$$   $$$$             $    $$$$$  $$$$$     $     $$$ 
                     $   $  $   $  $   $           $$        $  $        $$    $   $
                     $   $  $   $  $   $          $ $       $   $$$$    $ $        $
                     $   $  $$$$   $$$$             $      $        $  $  $       $$
                     $   $  $   $  $                $     $         $  $$$$$   $ 
                      $ $   $   $  $                $     $     $   $     $   $
                       $    $$$$   $       $$$$$  $$$$$   $      $$$      $   $$$$$
                                  DEST=VBP←175426003  USER=VBP←175426003  QUEUE=LP
                                      SEQ=9529  QPRI=191  LPP=66  CPL=132  COPIES=

                                                   CREATED:  19-DEC-79  16:28:30
                                                  ENQUEUED:  11-JUL-80   8:14:16
                                                  PRINTING:  11-JUL-80   8:19:11

                                                  PATH=:UDD:VBP←175426003:WRT5BE

                                             $   $  $$$$   $$$$$  $$$$$  $$$$   $$
                                             $   $  $   $    $    $      $   $  $
                                             $   $  $   $    $    $$$$   $   $  $
                                             $ $ $  $$$$     $        $  $$$$   $$
                                             $ $ $  $ $      $        $  $   $  $
                                             $$ $$  $  $     $    $   $  $   $  $
                                             $   $  $   $    $     $$$   $$$$   $$
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                                                  SOUTHWEST RESEARCH INST. DIV 17

                                                           AOS REV 03.04
                                                        AOS XLPT REV 03.04
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```
      SUBROUTINE WRTSBE(N11,N51,N61,NOUT,ISW1,N71)
      COMMON LIST(400,28)
      IF(ISW1.EQ.0) GO TO 10
      GO TO 20
   10 WRITE(NOUT,701) N11
  701 FORMAT(' PLANT NUMBER IS ' I2  )
   20 WRITE(NOUT,702)
  702 FORMAT(' ' 11X,'BROAD CLASSIFICATION' 22X,'GENERIC GROUPS' 26X,
     1'APPLICATION'    )
      IF(N51.LE.0) GO TO 30
      IF(N51.GT.9) GO TO 30
      GO TO 40
   30 WRITE(NOUT,703)
  703 FORMAT(11X,' UNIDENTIFIED' 27X,  Z  )
      GO TO 55
   40 GO TO (50,100,150,200,250,300,350,400,450) ,N51
   50 WRITE(NOUT,711)
  711 FORMAT(11X,' PUMPS(WITHOUT MOTOR)' 20X, Z )
      IF(N61.LE.0) GO TO 55
      IF(N61.GT.14)GO TO 55
      GO TO 60
   55 WRITE(NOUT,720)
  720 FORMAT( '+UNIDENTIFIED' 27X, Z )
      GO TO 500
   60 GO TO (62,64,66,68,70,72,74,76,78,80,82,84,86,88 ) ,N61
   62 WRITE(NOUT,721)
  721 FORMAT('+SELF PRIMING CENTRIFUGAL PUMP' 10X, Z )
      GO TO 500
   64 WRITE(NOUT,722)
  722 FORMAT('+SUBMERSIBLE CENTRIFUGAL PUMP'  11X, Z )
      GO TO 500
   66 WRITE(NOUT,723)
  723 FORMAT(  '+SCREW PUMP'  29X, Z )
      GO TO 500
   68 WRITE(NOUT,724)
  724 FORMAT(  '+PROGRESSING CAVITY PUMP' 16X, Z )
      GO TO 500
   70 WRITE(NOUT,725)
  725 FORMAT(  '+DIAPHRAM PUMP'  26X, Z  )
      GO TO 500
   72 WRITE(NOUT,726)
  726 FORMAT(  '+PISTON PUMP'  28X, Z  )
      GO TO 500
   74 WRITE(NOUT,727)
  727 FORMAT(  '+GEAR PUMP'  30X, Z  )
      GO TO 500
   76 WRITE(NOUT,728)
  728 FORMAT(  '+AIR OPERATED PUMP' 22X, Z  )
      GO TO 500
   78 WRITE(NOUT,729)
  729 FORMAT(  '+OPEN IMPELLER CENTRIFUGAL PUMP'  9X,  Z   )
      GO TO 500
   80 WRITE(NOUT,730)
  730 FORMAT(  '+CLOSED IMPELLER CENTRIFUGAL PUMP' 7X, Z   )
      GO TO 500
   82 WRITE(NOUT,731)
  731 FORMAT(  '+OPEN IMPELLER CENTRIFUGAL CLOSE CPLED' 4X, Z  )
      GO TO 500
   84 WRITE(NOUT,732)
  732 FORMAT(  '+CLOSED IMPELLER CENTRIFUGAL CLOSE CPLED' 2X,Z   )
      GO TO 500
   86 WRITE(NOUT,733)
  733 FORMAT(  '+PUMP WITH INTEGRAL MOTOR'  25X,  Z   )
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```
      GO TO 500
   88 WRITE(NOUT,89)
   89 FORMAT(   '+PROPELLER,AXIAL FLOW' 29X,   Z  )
      GO TO 500
  100 WRITE(NOUT,712)
  712 FORMAT(11X,' POWER TRANSMISSION' 25X,  Z  )
  105 IF(N61.LE.0) GO TO 55
      IF(N61.GT.12) GO TO 55
  120 GO TO (122,124,126,128,130,132,134,136,138,140,142,144),N61
  122 WRITE(NOUT,735)
  735 FORMAT(  '+CONCENTRIC REDUCER'  21X ,  Z  )
      GO TO 500
  124 WRITE(NOUT,736)
  736 FORMAT(  '+PARALLEL SHAFT' 25X,  Z  )
      GO TO 500
  126 WRITE(NOUT,737)
  737 FORMAT(  '+RIGHT-ANGLE SHAFT' 22X,  Z  )
      GO TO 500
  128 WRITE(NOUT,738)
  738 FORMAT(  '+VERTICAL SHAFT'  25X,  Z    )
      GO TO 500
  130 WRITE(NOUT,739)
  739 FORMAT(  '+VARIABLE SPEED DRIVE BELT TYPE' 9X, Z  )
      GO TO 500
  132 WRITE(NOUT,740)
  740 FORMAT(  '+VARIABLE SPEED DRIVE HYDRAULIC' 9X, Z  )
      GO TO 500
  134 WRITE(NOUT,741)
  741 FORMAT(  '+VARIABLE SPEED DRIVE OTHER'  13X,  Z  )
      GO TO 500
  136 WRITE(NOUT,742)
  742 FORMAT(  '+GEAR BOX' 31X,  Z   )
      GO TO 500
  138 WRITE(NOUT,743)
  743 FORMAT(  '+CHAIN DRIVE' 28X,  Z   )
      GO TO 500
  140 WRITE(NOUT,744)
  744 FORMAT(  '+CYCLO DRIVE- WEMCO SELLS' 15X,  Z   )
      GO TO 500
  142 WRITE(NOUT,745)
  745 FORMAT(  '+BELT DRIVE'  29X,  Z   )
      GO TO 500
  144 WRITE(NOUT,746)
  746 FORMAT(   '+FLEXIBLE COUPLING'  22X,   Z   )
      GO TO 500
  150 WRITE(NOUT,713)
  713 FORMAT(11X,' MOTORS' 37X,  Z    )
  155 IF(N61.LE.0) GO TO 55
      IF(N61.GT.8) GO TO 55
  160 GO TO (162,164,166,168,170,172,174,176) ,N61
  162 WRITE(NOUT,747)
  747 FORMAT( '+SINGLE PHASE' 27X, Z   )
      GO TO 500
  164 WRITE(NOUT,748)
  748 FORMAT(  '+MULTI PHASE' 28X, Z   )
      GO TO 500
  166 WRITE(NOUT,749)
  749 FORMAT(  '+AIR DRIVE'  30X,  Z  )
      GO TO 500
  168 WRITE(NOUT,750)
  750 FORMAT(  '+HYDRAULIC DRIVE' 24X,  Z  )
      GO TO 500
  170 WRITE(NOUT,751)
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751 FORMAT(  '+VARIABLE SPEED,AC' 22X,  Z   )
    GO TO 500
172 WRITE(NOUT,752)
752 FORMAT(  '+VARIABLE SPEED,DC' 23X,  Z   )
    GO TO 500
174 WRITE(NOUT,753)
753 FORMAT(   '+DC EXCITER'  29X,  Z   )
    GO TO 500
176 WRITE(NOUT,754)
754 FORMAT(  '+GAS ENGINE'   29X,  Z  )
    GO TO 500
200 WRITE(NOUT,714)
714 FORMAT(11X,' COMPRESSORS' 32X,  Z   )
205 IF(N61.LE.0) GO TO 55
    IF(N61.GT.6) GO TO 55
220 GO TO (222,224,226,228,230,232) ,N61
222 WRITE(NOUT,760)
760 FORMAT(  '+SINGLE STAGE CENTRIFUGAL' 15X, Z   )
    GO TO 500
224 WRITE(NOUT,761)
761 FORMAT(  '+MULTI STAGE CENTRIFUGAL'  16X, Z   )
    GO TO 500
226 WRITE(NOUT,762)
762 FORMAT(  '+ROTARY LOBE' 28X,  Z  )
    GO TO 500
228 WRITE(NOUT,763)
763 FORMAT(  '+ROTARY VANE' 28X,  Z  )
    GO TO 500
230 WRITE(NOUT,764)
764 FORMAT(  '+ROTARY WATER SEAL RING' 17X, Z   )
    GO TO 500
232 WRITE(NOUT,765)
765 FORMAT(  '+MULTI STAGE HIGH PRESSURE' 14X, Z   )
    GO TO 500
250 WRITE(NOUT,715)
715 FORMAT(11X,' DIFFUSERS AIR/WATER' 24X, Z   )
255 IF(N61.LE.0) GO TO 55
    IF(N61.GT.8) GO TO 55
270 GO TO (272,274,276,278,280,282,284,286) ,N61
272 WRITE(NOUT,770)
770 FORMAT(  '+SPARGERS,LARGE BUBBLE,MECHANICAL' 7X, Z   )
    GO TO 500
274 WRITE(NOUT,771)
771 FORMAT(  '+SMALL BUBBLE CERAMIC'  24X,  Z   )
    GO TO 500
276 WRITE(NOUT,772)
772 FORMAT(  '+SMALL BUBBLE PLASTIC'  24X,  Z   )
    GO TO 500
280 WRITE(NOUT,774)
774 FORMAT(  '+STATIC TUBE' 28X,  Z   )
    GO TO 500
282 WRITE(NOUT,775)
775 FORMAT(  '+CIRCULAR (FOR MECHANICAL AERATORS)' 6X, Z   )
    GO TO 500
284 WRITE(NOUT,776)
776 FORMAT(  '+RBC SHAFT'  31X,  Z  )
    GO TO 500
278 WRITE(NOUT,773)
773 FORMAT(  '+SMALL BUBBLE MECHANICAL' 16X, Z   )
    GO TO 500
286 WRITE(NOUT,777)
777 FORMAT(  '+WASTE TO MEDIA'   26X,   Z  )
    GO TO 500
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300 WRITE(NOUT,716)
716 FORMAT(11X,' VALVES' 37X, Z    )
305 IF(N61.LE.0) GO TO 55
    IF(N61.GT.9) GO TO 55
320 GO TO (322,324,326,328,330,332,334,336,338), N61
322 WRITE(NOUT,780)
780 FORMAT(  '+GATE' 35X, Z )
    GO TO 500
324 WRITE(NOUT,781)
781 FORMAT(  '+BALL' 35X, Z )
    GO TO 500
326 WRITE(NOUT,782)
782 FORMAT(  '+BUTTERFLY' 30X, Z   )
    GO TO 500
328 WRITE(NOUT,783)
783 FORMAT(  '+GLOBE' 34X,  Z )
    GO TO 500
330 WRITE(NOUT,784)
784 FORMAT(  '+NEEDLE' 33X, Z  )
    GO TO 500
332 WRITE(NOUT,785)
785 FORMAT(  '+RELIEF (SAFETY)' 24X,  Z  )
    GO TO 500
334 WRITE(NOUT,786)
786 FORMAT(  '+CHECK' 34X, Z  )
    GO TO 500
336 WRITE(NOUT,787)
787 FORMAT( '+SLUICE GAGE' 28X,  Z   )
    GO TO 500
338 WRITE(NOUT,788)
788 FORMAT(  '+PLUG' 35X,  Z   )
    GO TO 500
350 WRITE(NOUT,717)
717 FORMAT(11X,' CONTROLS'  37X, Z  )
355 IF(N61.LE.0) GO TO 55
    IF(N61.GT.5) GO TO 55
370 GO TO (372,374,376,378,379) ,N61
372 WRITE(NOUT,791)
791 FORMAT(  '+ELECTRICAL' 29X,  Z )
    GO TO 500
374 WRITE(NOUT,792)
792 FORMAT(  '+MECHANICAL' 29X,  Z )
    GO TO 500
376 WRITE(NOUT,793)
793 FORMAT(  '+PRESSURE (FLUID)' 23X,  Z  )
    GO TO 500
378 WRITE(NOUT,794)
794 FORMAT(  '+PRESSURE- AIR'    25X,  Z  )
    GO TO 500
379 WRITE(NOUT,795)
795 FORMAT(  '+CHLORINATORS'  27X,  Z  )
    GO TO 500
400 WRITE(NOUT,718)
718 FORMAT(11X,' PRESSURE VESSELS' 25X,  Z  )
405 IF(N61.LE.0) GO TO 55
    IF(N61.GT.2) GO TO 55
420 GO TO (422,424) ,N61
422 WRITE(NOUT,801)
801 FORMAT(  '+CHEMICAL CONTAINERS' 20X,  Z  )
    GO TO 500
424 WRITE(NOUT,802)
802 FORMAT( '+REACTORS'  31X,  Z   )
    GO TO 500
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450 WRITE(NOUT,719)
719 FORMAT(11X,' CONVEYER (UNCONFINED MATERIALS HANDLING)' 3X, Z  )
455 IF(N61.LE.0) GO TO 55
    IF(N61.GT.7) GO TO 55
460 GO TO (462,464,466,468,470,472,473) ,N61
462 WRITE(NOUT,901)
901 FORMAT(  '+BELT' 35X, Z  )
    GO TO 500
464 WRITE(NOUT,902)
902 FORMAT( '+SCREW' 34X, Z  )
    GO TO 500
466 WRITE(NOUT,903)
903 FORMAT(  '+PNEUMATIC' 30X,  Z  )
    GO TO 500
468 WRITE(NOUT,904)
904 FORMAT(  '+BUCKET' 33X,  Z  )
    GO TO 500
470  WRITE(NOUT,905)
905 FORMAT(  '+CHAIN (BAR SCREEN)'  21X,  Z  )
    GO TO 500
472 WRITE(NOUT,906)
906 FORMAT(  '+SKIMMER' 32X, Z  )
    GO TO 500
473 WRITE(NOUT,907)
907 FORMAT(  '+SLUDGE COLLECTOR'  23X,  Z )
500 CONTINUE
510 IF(N71.LE.0) GO TO 520
    IF(N71.GT.20) GO TO 530
    K1=N71
    GO TO 600
520 WRITE(NOUT,501) N71
501 FORMAT(  '+UNDEFINED' 3X,13   )
    GO TO 1000
530 IF(N71.LT.30) GO TO 520
    IF(N71.GT.34) GO TO 540
    K1=N71-29
    GO TO 700
540 IF(N71.LT.50) GO TO 520
    IF(N71.GT.52) GO TO 850
    K1=N71-49
    GO TO 800
600 GO TO (602,604,606,608,610,612,614,616,618,620,622,624,626,628,630
   1,632,634,636,638,640) ,K1
602 WRITE(NOUT,601)
601 FORMAT(  '+FLOW MEASUREMENT'    )
    GO TO 1000
604 WRITE(NOUT,603)
603 FORMAT(  '+RAW WASTEWATER PUMPING'   )
    GO TO 1000
606 WRITE(NOUT,605)
605 FORMAT(  '+INTERMEDIATE WASTEWATER PUMPING'   )
    GO TO 1000
608 WRITE(NOUT,607)
607 FORMAT(  '+SCREENING/COMMINUTION'    )
    GO TO 1000
610 WRITE(NOUT,609)
609 FORMAT(  '+GRIT REMOVAL'   )
    GO TO 1000
612 WRITE(NOUT,611)
611 FORMAT(  '+CLARIFIER CIRCULAR CENTER DRIVE'   )
    GO TO 1000
614 WRITE(NOUT,613)
613 FORMAT(  '+CLARIFIER CIRCULAR PERIPHERAL DRIVE'    )
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      GO TO 1000
  618 WRITE(NOUT,617)
  617 FORMAT(  '+CLARIFIER SQUARE/RECTANGULAR PERIPHERAL DR'    )
      GO TO 1000
  616 WRITE(NOUT,615)
  615 FORMAT(  '+CLARIFIER SQUARE/RECTANGULAR CENTER DRIVE'     )
      GO TO 1000
  620 WRITE(NOUT,619)
  619 FORMAT(  '+SCUM AND GREASE REMOVAL'    )
      GO TO 1000
  622 WRITE(NOUT,621)
  621 FORMAT(  '+RETURN ACTIVATED SLUDGE HANDLING'    )
      GO TO 1000
  624 WRITE(NOUT,623)
  623 FORMAT(  '+RECIRCULATION PUMPING'      )
      GO TO 1000
  626 WRITE(NOUT,625)
  625 FORMAT(  '+OXYGEN GENERATION/STORAGE'    )
      GO TO 1000
  628 WRITE(NOUT,627)
  627 FORMAT(  '+DISSOLVED AIR PRODUCTION'    )
      GO TO 1000
  630 WRITE(NOUT,629)
  629 FORMAT(  '+DISSOLVED AIR/O2 APPLICATION'    )
      GO TO 1000
  632 WRITE(NOUT,631)
  631 FORMAT(  '+TRICKLING FILTER ROTARY DISTRIBUTOR'    )
      GO TO 1000
  634 WRITE(NOUT,633)
  633 FORMAT(  '+DOSING SIPHON'    )
      GO TO 1000
  636 WRITE(NOUT,635)
  635 FORMAT(  '+TRICKLING FILTER FIXED DISTRIBUTOR'    )
      GO TO 1000
  638 WRITE(NOUT,637)
  637 FORMAT(  '+ROTATING BIOLOGICAL CONTACTOR'  )
      GO TO 1000
  640 WRITE(NOUT,639)
  639 FORMAT(  '+MECHANICAL AERATORS'   )
      GO TO 1000
  700 GO TO (704,706,708,710,1050) ,K1
  704 WRITE(NOUT,641)
  641 FORMAT(  '+PRIMARY SLUDGE PUMPING'  )
      GO TO 1000
  706 WRITE(NOUT,643)
  643 FORMAT(  '+SECONDARY SLUDGE PUMPING'    )
      GO TO 1000
  708 WRITE(NOUT,645)
  645 FORMAT(  '+WASTE ACTIVATED SLUDGE PUMPING'  )
      GO TO 1000
  710 WRITE(NOUT,647)
  647 FORMAT(  '+OTHER SLUDGE PUMPING'    )
      GO TO 1000
 1050 WRITE(NOUT,648)
  648 FORMAT(  '+DIGESTER GAS RECIRCULATION PUMPING'    )
      GO TO 1000
  800 GO TO (810,820,830) ,K1
  810 WRITE(NOUT,650)
  650 FORMAT(  '+CHLORINE,GASEOUS'    )
      GO TO 1000
  820 WRITE(NOUT,651)
  651 FORMAT(  '+CHLORINE,HYPO'  )
      GO TO 1000
 830 WRITE(NOUT,652)
 652 FORMAT(  '+OTHER,O3,UV,BR2'  )
     GO TO 1000
 850 IF(N71.LT.61) GO TO 520
     IF(N71.GT.66) GO TO 520
     K1=N71-60
 900 GO TO (910,920,930,940,950,960) ,K1
 910 WRITE(NOUT,661)
 661 FORMAT(  '+HIGH SPEED FIXED'   )
     GO TO 1000
 920 WRITE(NOUT,662)
 662 FORMAT(  '+LOW SPEED FIXED'    )
     GO TO 1000
 930 WRITE(NOUT,663)
 663 FORMAT(  '+HIGH SPEED FLOATING'   )
     GO TO 1000
 940 WRITE(NOUT,664)
 664 FORMAT(  '+LOW SPEED FLOATING'   )
     GO TO 1000
 950 WRITE(NOUT,665)
 665 FORMAT(  '+SUBMERGED TURBINE'  )
     GO TO 1000
 960 WRITE(NOUT,666)
 666 FORMAT(  '+FIXED ROTOR'   )
1000 CONTINUE
     RETURN
     END
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                      $   $  $$$$   $$$$            $    $$$$$  $$$$$     $    $$$
                      $   $  $   $  $   $          $$        $  $          $$   $   $
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                                                  SOUTHWEST RESEARCH INST. DIV 17


                                                           AOS REV 03.04
                                                        AOS XLPT REV 03.04
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      SUBROUTINE WRT8BE(N81,NU,TH,NFR,PMY,CMY,XMTTR,XTRF1,XTRF2,NOUT,
     -AVI,AVO)
      COMMON LIST(400,28)
      K1=N81
      IF(K1.LE.0) GO TO 10
      IF(K1.GT.25) GO TO 10
      GO TO 20
   10 WRITE(NOUT,950)
  950 FORMAT(   ' UNDEFINED' 21X,  Z  )
      GO TO 100
   20 GO TO (21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40
     1,41,42,43,44,45) ,K1
   21 WRITE(NOUT,951)
  951 FORMAT(  ' 0-10000 GAL. PER MIN.'      9X,     Z  )
      GO TO 100
   22 WRITE(NOUT,952)
  952 FORMAT(  ' 10001-20000 GAL. PER MIN.'     5X,    Z )
      GO TO 100
   23 WRITE(NOUT,953)
  953 FORMAT( ' 20001-100000 GAL. PER MIN.'    4X,    Z  )
      GO TO 100
   24 WRITE(NOUT,954)
  954 FORMAT(  ' OVER 100000 GAL. PER MIN.'     5X,  Z )
      GO TO 100
   25 WRITE(NOUT,955)
  955 FORMAT(  ' 0-1 HORSEPOWER' 16X,  Z  )
      GO TO 100
   26 WRITE(NOUT,956)
  956 FORMAT(  ' 1-5 HORSEPOWER' 16X,  Z  )
      GO TO 100
   27 WRITE(NOUT,957)
  957 FORMAT(  ' 6-25 HORSEPOWER' 15X, Z  )
      GO TO 100
   28 WRITE(NOUT,958)
  958 FORMAT(  ' 26-100 HORSEPOWER' 13X, Z )
      GO TO 100
   29 WRITE(NOUT,959)
  959 FORMAT(  ' 101-500 HORSEPOWER' 12X, Z )
      GO TO 100
   30 WRITE(NOUT,960)
  960 FORMAT(  ' OVER 500 HORSEPOWER' 11X, Z  )
      GO TO 100
   31 WRITE(NOUT,961)
  961 FORMAT(  ' 0-10 CFM' 22X, Z )
      GO TO 100
   32 WRITE(NOUT,962)
  962 FORMAT(  ' 11-20 CFM' 21X, Z )
      GO TO 100
   33 WRITE(NOUT,963)
  963 FORMAT(  ' 21-25 CFM' 21X, Z )
      GO TO 100
   34 WRITE(NOUT,964)
  964 FORMAT(  ' 26-100 CFM' 20X, Z )
      GO TO 100
   35 WRITE(NOUT,965)
  965 FORMAT(  ' 101-1000 CFM' 18X, Z )
      GO TO 100
   36 WRITE (NOUT,966)
  966 FORMAT(  ' 1001-10000 CFM' 16X, Z )
      GO TO 100
   37 WRITE(NOUT,967)
  967 FORMAT(  ' 10001-20000 CFM' 15X, Z )
      GO TO 100
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 38 WRITE(NOUT,968)
968 FORMAT(  ' OVER 20000 CFM' 16X,  Z )
    GO TO 100
 39 WRITE(NOUT,969)
969 FORMAT(  ' 0-6 INCHES' 20X, Z  )
    GO TO 100
 40 WRITE(NOUT,970)
970 FORMAT(  ' 7-12 INCHES' 19X, Z  )
    GO TO 100
 41 WRITE(NOUT,971)
971 FORMAT(  ' 13-24 INCHES' 18X, Z  )
    GO TO 100
 42 WRITE(NOUT,972)
972 FORMAT(  ' 25-48 INCHES' 18X, Z  )
    GO TO 100
 43 WRITE(NOUT,973)
973 FORMAT(  ' OVER 48 INCHES' 16X, Z  )
    GO TO 100
 44 WRITE(NOUT,974)
974 FORMAT(  ' 0-2000 LBS CHEMICAL' 11X,  Z  )
    GO TO 100
 45 WRITE(NOUT,975)
975 FORMAT(  ' OVER 2000 LBS CHEMICAL' 8X, Z  )
100 WRITE(NOUT,980) NU,TH,NFR,PMY,CMY,XMTTR,XTBF1,XTBF2,AVI,AVO
980 FORMAT(  '+' , I5,2X,E9.4,2X,I5,7(2X,E9.4)  )
    RETURN
    END
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                          $   $  $$$$   $$$$            $    $$$$$  $$$$$     $    $$$
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                                                         SOUTHWEST RESEARCH INST. DIV 17


                                                                   AOS REV 03.04
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1   1   1000000000000000000000000000000000000000000000000000000000000
1   1   2000000000000000000000000000000000000000000000000000000000000
1   2   3   5   3   4   5   6   7000000000000000000000000000000000000
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